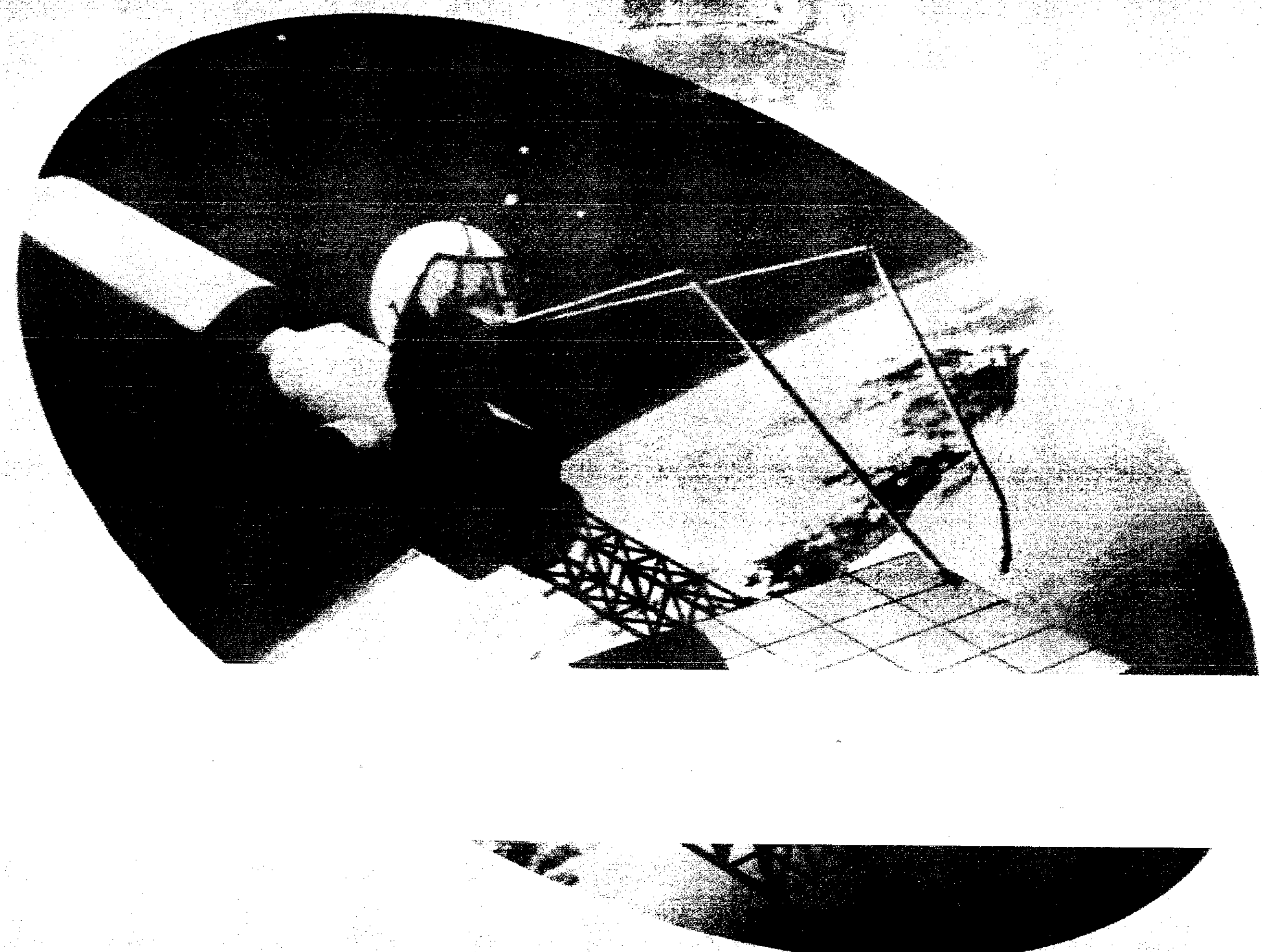
IN-SPACE RESEARCH, TECHNOLOGY AND ENGINEERING (RT&E) WORKSHOP

VOLUME 1 OF 8

EXECUTIVE SUMMARY



NATIONAL CONFERENCE CENTER
WILLIAMSBURG, VIRGINIA
OCTOBER 8-10, 1985

NASA
National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia 23665

OAST
Office of Aeronautics
and Space Technology
Washington, DC

NOTICE

The results of the OAST Research, Technology, and Engineering Workshop which was held at the National Conference Center, Williamsburg, Virginia, October 8-10, 1985 are contained in the following reports:

VOL 1	Executive Summary
VOL 2	Space Structure (Dynamics and Control)
VOL 3	Fluid Management
VOL 4	Space Environmental Effects
VOL 5	Energy Systems and Thermal Management
VOL 6	Information Systems
VOL 7	Automation and Robotics
VOL 8	In-Space Operations

Copies of these reports may be obtained by contacting:

NASA Langley Research Center
Attn: 288/Dr. Roger A. Breckenridge
Hampton, VA 23665

Commercial Telephone: (804) 865-4834
Federal Telephone System: 928-4834

GENERAL CHAIRMAN

Dr. Raymond S. Colladay
Associate Administrator
for Aeronautics and Space Technology
NASA Headquarters

TECHNICAL PROGRAM CO-CHAIRMEN

Dr. Leonard A. Harris
Director for Space
Office of Aeronautics and Space Technology
NASA Headquarters

and

James M. Romero
Assistant Director for Space (Space Station Technology)
Office of Aeronautics and Space Technology
NASA Headquarters

TECHNICAL COORDINATORS

Dr. Roger A. Breckenridge and Richard A. Russell
Space Station Office
NASA Langley Research Center

TECHNICAL PROGRAM SUPPORT

Floyd Roberson
(202) 547-2506
USRA
Washington, DC

ADMINISTRATIVE SUPPORT

Robert L. Wright
Mail Stop 364
(804) 865-2487

and

Kay Millen
Mail Stop 288
(804) 865-4834

NASA Langley Research Center

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FOREWORD

FOREWORD

Within NASA, the Office of Aeronautics and Space Technology (OAST) has the responsibility for timely development of needed new technologies. Traditionally, the development of new concepts, new materials, designs, and engineering techniques for aeronautics has been accomplished in close cooperation with the aircraft industry and with the great American universities. On the other hand, NASA, as the primary user of space flight, has been its own principal customer for new space technologies.

A new era of permanent presence in space is beginning with the Space Station. This permanent presence will permit and promote commercial ventures and privately funded research in the tradition of university/industry cooperation.

The RT&E workshop in Williamsburg represents a significant milestone for NASA and the space engineering community. It marked the initiation of a long-term program of outreach by NASA to focus the needs of universities, industry, and government for in-space experiments and to begin building a strong national user constituency for space research and engineering.

These proceedings represent a "first-cut" planning activity to involve universities, industry, and other government agencies with NASA to establish structure and content for a national in-space RT&E program. More interactions are needed - more workshops will follow. Program adjustments will be made. A truly national program will evolve, and its beginnings are presented here with the hope and determination needed to make it a program we can all take pride in.

- Raymond Colladay

INTRODUCTION

INTRODUCTION

Among the purposes of the Research, Engineering, and Technology Workshop, an interest in validating the RT&E theme concept has some direct effect on the form of these proceedings. The original five themes, which were themselves a target for validation or recommeded changes, have become seven. During preparations for the workshop, the submitted papers and attendance plans made it evident that the fifth "theme", In-space Operations, was too broad, and would need to be split. As the workshop got underway, a further split occurred, brought about by the different levels of maturity, and needs for technology planning in several sub-disciplines. Thus, these proceedings are presented under seven themes. The volume of presentations, and the quantity of information generated by the individual panel summaries has led to the decision to prepare the proceedings in several volumes.

The first volume is an executive summary and includes the summary presentations made by the panel co-chairmen in the final plenary session. The accompanying seven volumes, of which this is one, each represent a specific "theme", and include the un-edited original presentation material used in that particular panel workshop. Each of these separate "theme" volumes also include the Foreword, the general Summary and Conclusions, and the Chairman's presentation charts and narrative summary. Thus, each should represent a self-standing volume to reflect the proceedings relevant to its respective Panel deliberations and output, as well as the reflection in the general Workshop results.

The seven "themes" and their respective technical disciplines are presented on the following page for information. These themes will play an important role in planning the in-space experiments program of the future and, particularly, as it relates to Space Station utilization.

WORKSHOP THEMES

Space Structure (Dynamics & Control)

--Advanced Structural Concepts

--Structural Dynamics

--Advanced Control Concepts

--Structure/Control Interaction

--Structure/Control Sensors

Fluid Management

--Fuel Storage & Transfer

--Fluid Behavior

--Sensor Concepts

Space Environmental Effects

--Material Durability

  --Atomic Oxygen

  --Ultraviolet/Vacuum

  --Electron/Proton

--Plasma

--Contamination

Energy Systems & Thermal Management

--Advanced Photovoltaics

--Solar Dynamics

--Nuclear

--Advanced Thermal Concepts

--Laser Power

Information Systems

--Sensor Systems

--Computer/Data Systems

--Communications Systems

Automation & Robotics

--Mobility

--Dextrous Manipulation

--Supervise/Autonomous Robots

--Advanced Concepts

In-Space Operations

--Advanced Life Support System

--Biomedical Research

--Tethers

--Maintenance and Repair

--Orbital Transfer Vehicle

--System Testing

--Propulsion

--Material Processing

SUMMARY AND CONCLUSIONS

SUMMARY AND CONCLUSIONS

NASA's In-Space Research, Technology, and Engineering (RT&E) Workshop brought together representatives of the university community, private sector, and government agencies to discuss future needs for in-space experiments in support of space technology development and the derivative requirements for space station facilities to support in-space RT&E.

The workshop provided an excellent forum for establishing an interactive process for building a national in-space experiments program. It enabled NASA to present to the user community (university and private sector) experiment concepts for NASA's technology development activities in support of future space missions. The meetings also began a process by which industry and university researchers will be able to bring their own TDM requirements to NASA's planning process.

This conference reached three primary goals: first, it expanded and validated NASA's in-space experiment theme areas, including Space Structure (Dynamics and Control), Space Environmental Effects, Fluids Management, Energy Systems and Thermal Management, Automation and Robotics, Information Systems and In-Space Operations; second, it began the development of a user community network which will interface with NASA throughout the lifetime of the in-space experiment program; and third, it formed the basis for the establishment of on-going working groups which will continue to interest and coordinate requirements for in-space RT&E activities.

As an adjunct to the conference, NASA/OAST announced plans to initiate a long-term program to encourage and support industry and university experiments. NASA's modest investment in this program is initially targeted for generating experiment ideas and concepts. It is anticipated that this base of concepts will lead to cooperatively funded experiments between NASA, industry, and academia and thereby, begin to build an active in-space RT&E program.

Several key points emerged from this conference regarding the adequacy of the TDM data base that should be addressed in future planning activities. First, many of the experiments could be performed on the ground, i.e., they do not justify a space experiment. Secondly, many of the experiments address near-term or current applications and do not take into account advanced system requirements. The TDM data base must look beyond extensions of current programs to reflect future needs and trends to have an effective and useful impact on space station planning and design. This will require increased input from industry and university researchers and engineers.

In order to address these concerns, it is imperative that a long-range planning view be taken in which industry and university researchers help NASA derive the technology development program. The following recommendations have been developed on the basis of the workshop:

1. Development of an on-going RT&E university and industry advisory group;
2. Continuation of in-space RT&E symposia to act both as outreach mechanisms and as working sessions to refine the TDM data base;
3. Development of an RT&E information clearinghouse;
4. Development and continuation of the new experiments outreach activity announced at the RT&E workshop;
5. Development of an "impacts assessment group" which will focus its energy on identifying experiment accommodation requirements to impact the design of in-space facilities, i.e., space station and others.

If carried out, these recommendations constitute movement toward development of an effective NASA/industry/university partnership in a National In-Space RT&E Program. This will also enable NASA/OAST to have an effective voice in space station planning, which is essential toward the success of a future in-space activities. The workshop, by promoting the process of NASA/industry/university interactions and by pointing out concerns with the developing TDM data base has provided an important first step towards a successful long-term space technology development effort.

OPENING ADDRESSES

OPENING ADDRESSES

Keynote Address	John D. Hodge Deputy Associate Administrator OSS, NASA Headquarters
OAST Overview	Dr. Leonard A. Harris Director for Space, OAST, NASA Headquarters
Space Station Requirements and Configuration	Carl D. Shelley Manager, Customer Integration Office, SSPO, NASA Johnson Space Center
Workshop Objectives	James M. Romero Assistant Director for Space (Space Station Technology), OAST, NASA Headquarters

KEYNOTE ADDRESS

John D. Hodge

S/-18

208.

PRESIDENT RONALD REAGAN
STATE OF THE UNION MESSAGES

"We can follow our dreams to distant stars, living and working in space for peaceful, economic and scientific gain. Tonight, I am directing NASA to develop a permanently manned space station and to do it within a decade.

A space station will permit quantum leaps in our research in science, communications and in metals and life-saving medicines which can be manufactured ... in space."

January 25, 1984

"Our Second American Revolution will push on to new possibilities not only on Earth but in the next frontier of space. Despite budget restraints, we will seek record funding for research and development.

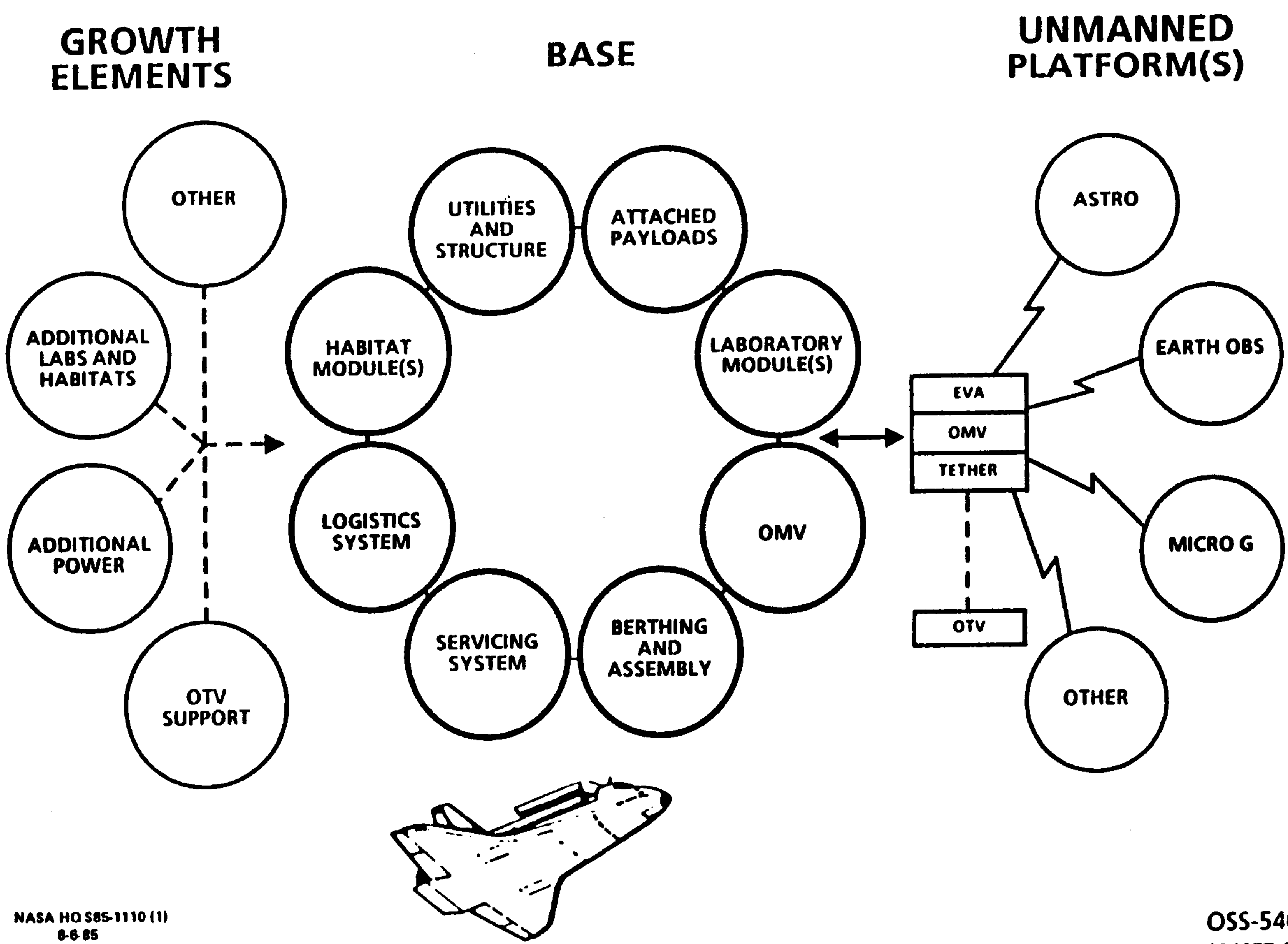
We have seen the success of the space shuttle. Now we are going to develop a permanently manned space station and new opportunities for free enterprise because in the next decade, Americans and our friends around the world will be living and working together in space."

February 6, 1985

FILE NAME: S/Reagan

NASA HQ S 2-11-85
(OSSTT 278)

SPACE STATION PROGRAM ARCHITECTURE



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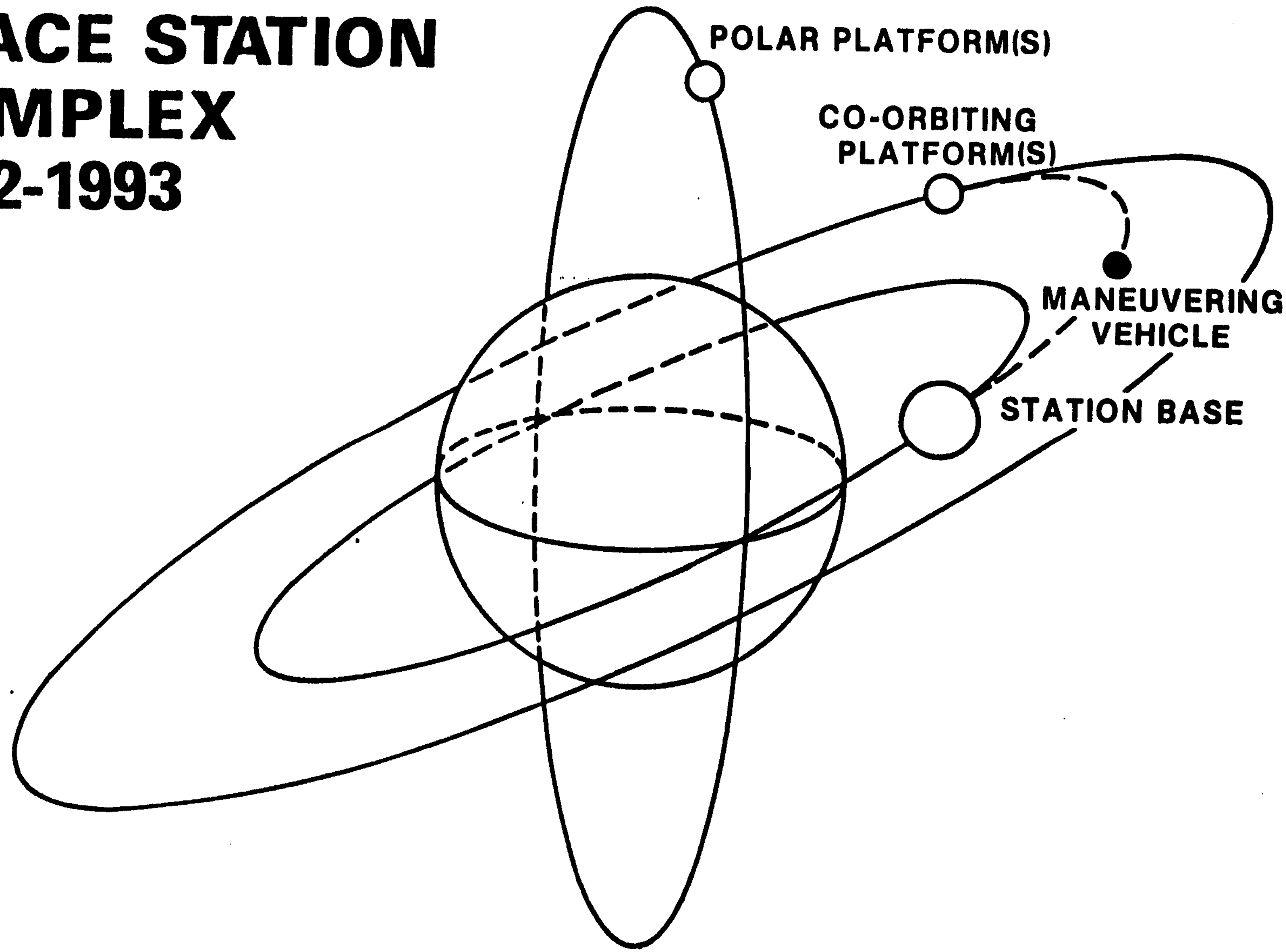
(OSSTT-2)

SPACE STATION COMPLEX 1992-1993



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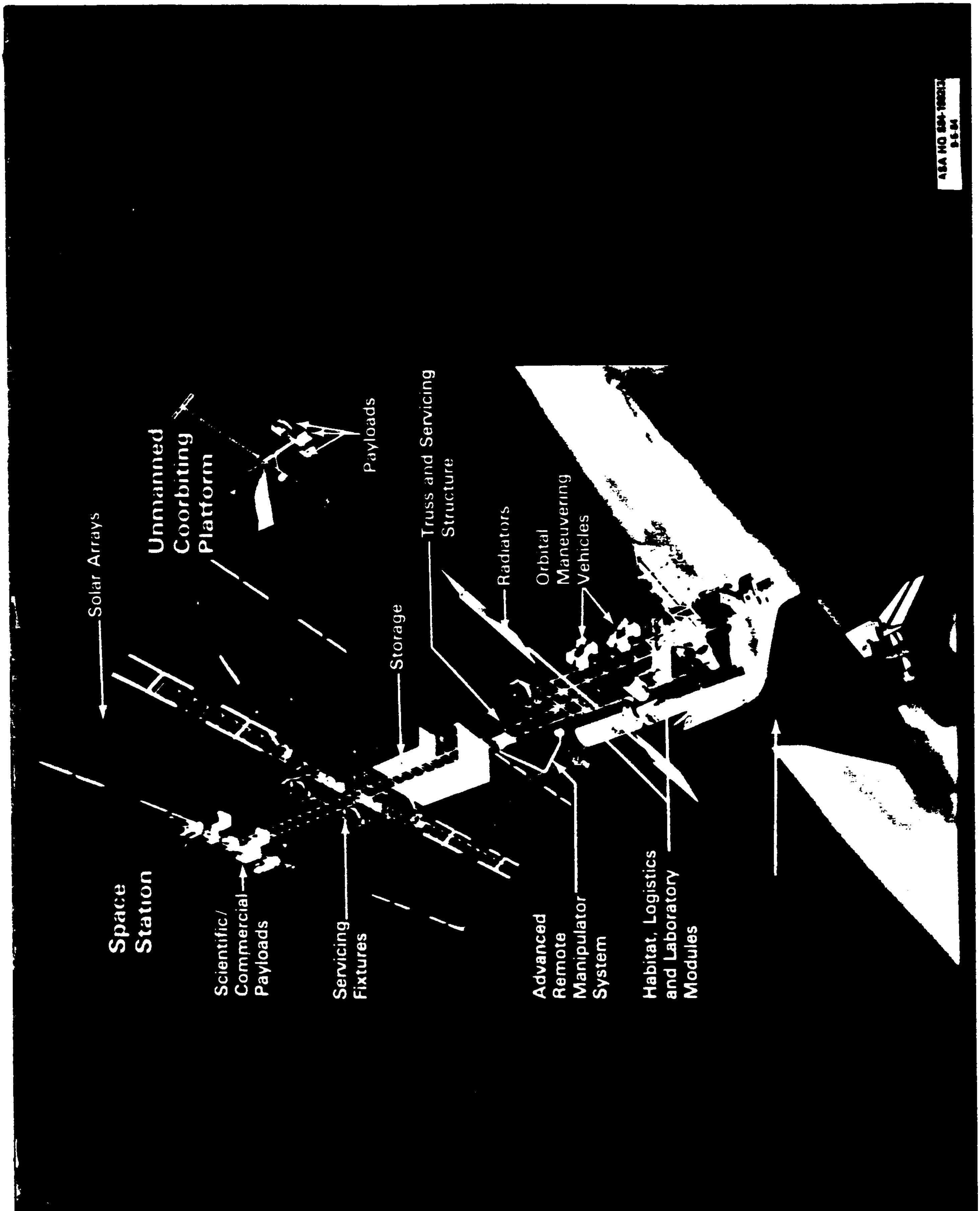


Space Station
Scientific/ Commercial Payloads
Servicing Fixtures
Advanced Remote Manipulator System
Habitat, Logistics and Laboratory Modules
Solar Arrays
Storage
Unmanned Coorbiting Platform
Payloads
Truss and Servicing Structure
Radiators
Orbital Maneuvering Vehicles

SPACE STATION BASELINE PARAMETERS

- Space Shuttle will be primary transportation system
- Canada, European Space Agency and Japan participate in Space Station program as genuine partners
- Space Station users are involved in definition and design
- Congress is encouraging enhancements in automation and robotics
- Department of Defense is not a participant in the Space Station program but is a potential user
- Space Station will be a "permanent" facility
- President directed NASA to develop the Space Station "within a decade"

FILE NAME: S/SpSIBPar

NASA HQ S 9-23-85

SPACE STATION PROGRAM
AUTOMATION AND ROBOTICS

- Space flight typically utilizes automation and robotics

- Advanced Technology Advisory Committee (ATAC)

- Three tiers of automation and robotics for Space Station:

  1. A&R typically employed

  2. Enhancement to expand Space Station capabilities

  3. Further enhancement in support of national A&R efforts

SPACE STATION PROGRAM

APPROACH TO LONG RANGE PLANNING

- Recognize Space Station is different
  - ''Permanent''
  - Permanently manned
  - $\boxed{\text{— Evolutionary}}$
- Involve non-NASA groups in planning
  - International partners
  - Users
  - Advisory groups
- Develop an operations concept at an early date
- Conduct technology development activities which support evolving use and requirements of the station
- Encourage and accommodate commercial utilization

SPACE STATION PROGRAM

LONG RANGE PLANNING FOR ENGINEERING

GOALS

- Develop a design for cost-effective, permanently manned Space Station to meet user needs and operational requirements
- Define "scar" requirements for initial Space Station to accommodate technological upgrade and evolutionary growth

APPROACH

- Evaluate and accommodate user requirements
- Establish the IOC Space Station design to accommodate the widest envelope of evolutionary scenarios
- Evaluate and forecast technological improvements to determine IOC Station scars to enable economical upgrade
- Understand requirements for facilities
- Evaluate productivity and automation technological development to enable performance improvement at reduced cost
- Evaluate operational scenario to determine improvements to increase performance at reduced cost
- Establish design changes to improve life and reduce cost

SPACE STATION PROGRAM

LONG RANGE PLANNING FOR INTERNATIONAL COOPERATION

GOALS

- Develop a single, integrated Space Station whose capabilities all will share
- Achieve a genuine partnership between U.S., Canada, ESA and Japan

APPROACH

- Incorporate international participants early on in U.S. planning
- Encourage partners to develop Space Station user interests
- Have partners participate in program across the board
  - Users
  - Operations
  - Engineering
- Exchange only technical information necessary to assure compatibility of systems
- Expect international partners to assume full financial and technical responsibility for their Space Station elements

FILE NAME: S/SpSILRPI

NASA HQ S 9-23-85

SPACE STATION PROGRAM

LONG RANGE PLANNING FOR UTILIZATION

GOALS

- Maximize utility of Space Station through incorporation of users requirements in Space Station definition and design
- Accommodate, fairly and efficiently, a variety of users. Encourage commercial users
- Serve as driver for direction of evolutionary capability
- Shape operations concept and requirements

APPROACH

- Continue to assure that user activities which might be enabled or enhanced by the Space Station have been identified
- Obtain from individual users and their sponsors better information on Space Station activities they would like to pursue
- Work with each community of users to better understand their requirements and their anticipated style of operating in the Space Station era
- Encourage, where appropriate, planning of cooperative research programs in order to assure the greatest return for both user and Space Station resources
- Work with the users, user sponsor and appropriate advisory committees to assure that we properly understand their requirements and are properly translating these requirements into Space Station design

SPACE STATION PROGRAM

LONG RANGE PLANNING FOR ADVANCED DEVELOPMENT

GOALS

- Develop those technologies that will enable enhanced productivity and cost effectiveness of the Space Station
- Assure that advanced technologies are available on a timely basis for the initial Station

APPROACH

- Select high leverage technologies for development
- Maintain multidisciplinary technology development programs:
  - Mature new technologies from generic research base
  - Utilize test beds to evaluate new technology
  - Extend flight experiment program on Shuttle and Space Station
- Establish a post IOC technology program to enable a phased transition of new technology for an evolutionary design
- Involve United States industry in a cooperative development program

FILE NAME: S/SpStLRPD

NASA HQ S 9-23-85

TECHNOLOGY DEVELOPMENT

MATERIALS AND STRUCTURES
- Materials performance and processing, deployment/assembly/construction, and structural dynamics

ENERGY CONVERSION
- Solar concentrator, laser power transmission/reception, waste heat rejection, and power subsystems

COMMUNICATIONS AND ELECTRONICS
- Space antenna, telecommunication systems, space interferometer systems, and Earth observations

PROPULSION
- Fluid management and low thrust propulsion

CONTROLS AND HUMAN FACTORS
- Figure controls and devices, information systems, teleoperation, and interactive human factors

SYSTEMS OPERATIONS
- Environmental effects, habitation, medical, tether systems, satellite and OTV servicing, and systems operations

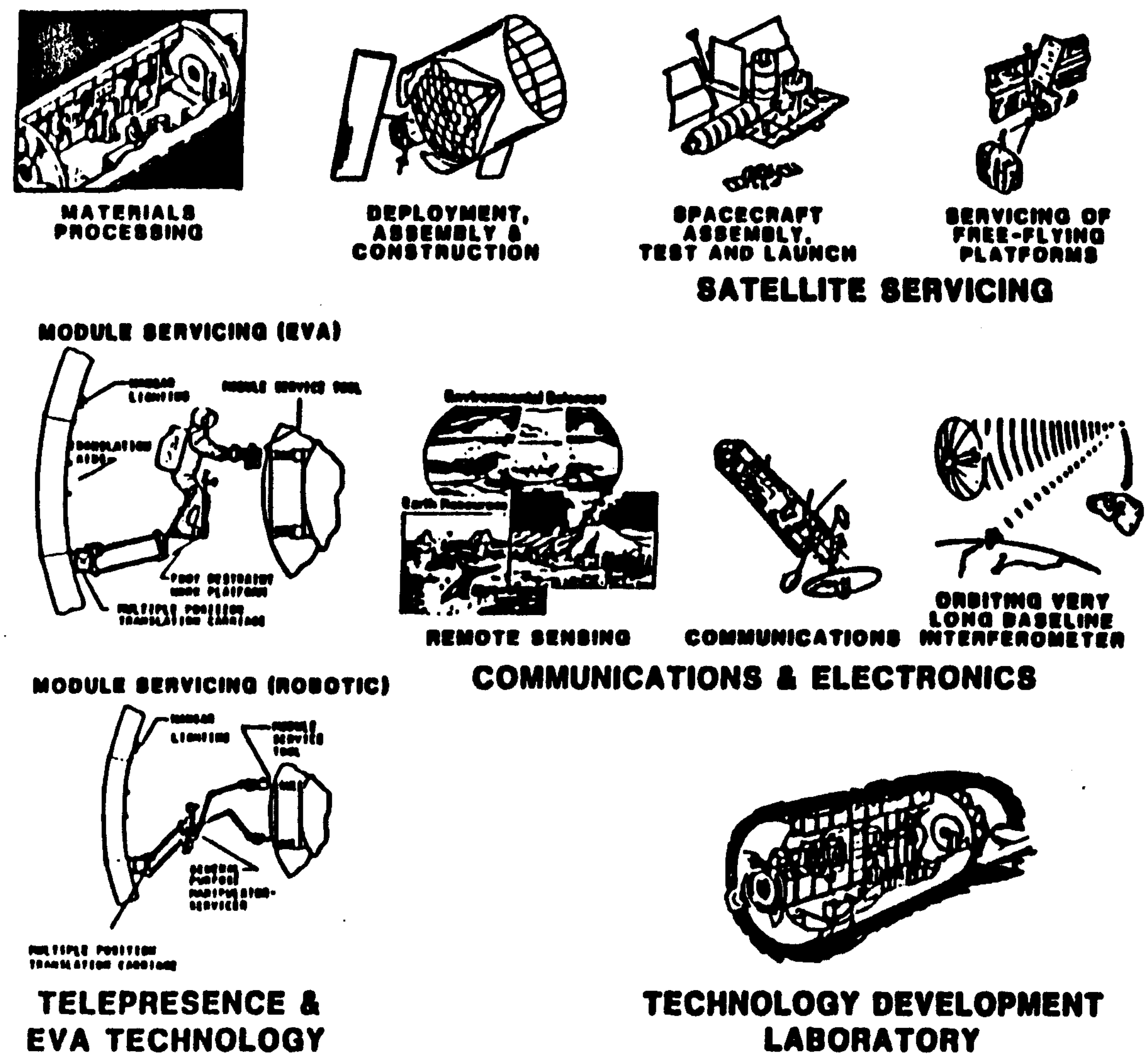
"Technology Development" is both a mission/payload category for the station and a program to provide new capabilities for its development and operations.

FILE NAME:S/TechDev

NASA HQ S 12-4-84
(OSSTT 18A)

TECHNOLOGY DEVELOPMENT MISSIONS

MISSIONS	
CODE	**NAME**
	MATERIALS & STRUCTURES
2010	Materials Performance
2020	Materials Processing
2060	Deployment/Assembly/Construction
2070	Structural Dynamics
	ENERGY CONVERSION
2110	Large Solar Concentrator
2120	Laser Power Transmission/Reception
2130	Waste Heat Rejection
2150	Power Subsystem
	COMMUNICATIONS & ELECTRONICS
2210	Large Space Antenna
2220	Telecommunications Systems
2230	Space Interferometer Systems
2260	Earth Observation
	PROPULSION
2310	Fluid Management
2320	Low Thrust Propulsion
	CONTROLS & HUMAN FACTORS
2410	Adaptive Controls
2420	Figure Control
2430	Control Devices
2440	Information Systems
2460	Teleoperation
2470	Interactive Human Factors
	SPACE STATION SYSTEM OPERATIONS
2510	Environmental Effects
2520	Habitation
2530	Medical
2540	Tether Systems
2560	Satellite Servicing
2570	OTV Servicing
2560	Systems Operations



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ANTICIPATED USER ACTIVITY
TECHNOLOGY DEVELOPMENT AND DEMONSTRATION

- INCLUDES AREAS OF:
  - Environmental effects
  - Large structures assembly and dynamics
  - Materials performance
  - Electrical power generation and storage techniques
  - Communications and data handling
  - Fluid management, transfer, and cryogenic storage
  - Attitude and figure control
  - Teleoperations and automation
  - Habitation, medical operations, and human factors
  - Tethers
  - Servicing
  - OMV and OTV capability enhancements
  - Solar concentrators

OSS-263

SPACE STATION EVOLUTION WORKSHOP

- **PURPOSE OF WORKSHOP WAS TO PROVIDE KNOWLEDGE BASE**
  - Potential evolution scars
  - Required trades
  - Technology development

- **SCENARIOS CONSIDERED**

  (1) Research and technology (Includes commercial as in data base)
  - Growth to present functional requirement envelope (FRE)

  (2) Commercial
  - Materials processing
  - GEO communications platforms
  - Earth observations

  (3) New initiative
  - Unmanned sample return
  - Manned lunar base
  - Manned Mars program

OSS-979

SPACE STATION EVOLUTION WORKSHOP
DISCIPLINE TECHNOLOGIES

- ATTITUDE CONTROL SYSTEM
  - Precision closed loop control for micro-G station keeping, pointing
  - Robustness for large mass/inertia changes
- COMMUNICATION & TRACKING
  - TDRSS channels capacity expansion (Ku)
  - High speed ground computers/high capacity storage
  - Possible Ka, w bands and/or optical (TDAS)
- DATA MANAGEMENT SYSTEM
  - Onboard storage and processing (high rate and capacity)
  - Automated remote servicing
- EXTRAVEHICULAR ACTIVITY
  - High productivity, space-based suit
- ENVIRONMENT CONTROL AND LIFE SUPPORT SYSTEM
  - Closed air/water
  - Waste processing
  - Long term CELLS option

OSS-980, 1 of 3

SPACE STATION EVOLUTION WORKSHOP
DISCIPLINE TECHNOLOGIES

- FLUIDS
  - Acquisition, transfer, storage
  - 2 phase separators for non-cryogens
  - Cryo fluid management
- MANNED SYSTEMS
  - Controls, displays for the human operator interface
  - Natural language for continuous speech recognition
  - Sensing and perception
- MATERIALS
  - Radiation protection
  - Hazardous materials handling
  - Debris and fire protection
- MECHANISMS
  - Vibration and shock isolation and attenuation
  - Mechanization for servicing
- POWER
  - High temperature solar engines
  - Nuclear

OSS-980, 2 of 3

SPACE STATION EVOLUTION WORKSHOP DISCIPLINE TECHNOLOGIES

- PROPULSION
  - H/O propulsion
  - High performance and long life; e.g., arc jets, high temperature resistojets
  - Biowaste
- STRUCTURES
  - Advanced aerobrake (OTV)
  - Large space structure <u>precision</u> assembly
  - "Composite" STS logistics system
- THERMAL
  - 3-D high temperature and high capacity heat pipes
  - Coatings
- AUTOMATION AND ROBOTICS
  - Servicing
  - Auto logistics and planning for commercialization
  - Interactive expert systems/diagnostics
  - Artificial intelligence
  - "Smart" robotics systems

OSS-980, 3 OF 3

SPACE STATION PROGRAM

LONG RANGE PLANNING FOR OPERATIONS

GOALS

- Incorporate operations factors in Space Station definition and design
- Provide safe, affordable and efficient operations for
  - Space Station systems
  - Users
- Accommodate evolution
- Encourage commercial activities

APPROACH

- Develop an operations concept and a set of operations requirements consistent with safe, efficient and effective operations
- Delineate phases of Space Station operations
  - Development
  - Assembly
  - Verification
  - Mature operations
  - Evolution
- Structure operations planning around
  - Market development
  - Direct Operations support to users
  - Space systems operations
  - Logistics support
  - Business management

FILE NAME: S/SpSILRPO

NASA HQ S 9-23-85

SPACE STATION PROGRAM

SELECTED CHALLENGES

- ***USERS:*** Accommodate multiple users whose requirements
  - Are not yet fully defined
  - Will change over time
  - Sometimes conflict with each other
  - Exceed Space Station initial capabilities

- ***TECHNOLOGY:*** Provide design that enables technological upgrade, one that is invisible to user

- ***ENGINEERING:*** Develop an integrated system that is
  - Capable of long life
  - Maintainable on orbit
  - Evolutionary in character

- ***MANAGEMENT:*** Orchestrate NASA Centers, industry teams and international partners, retaining effort in evolutionary systems while interest increasingly focuses on initial capability

SPACE STATION

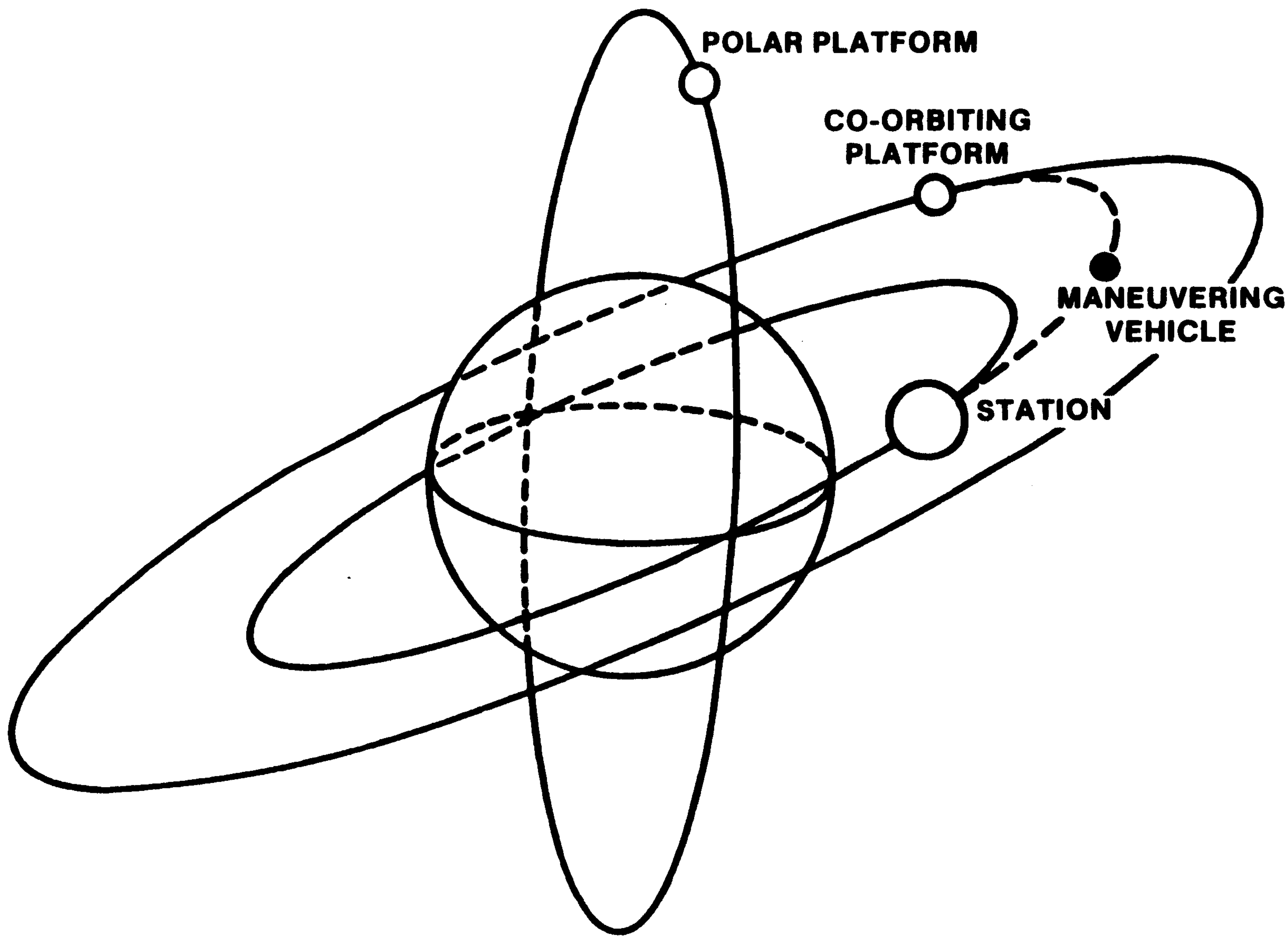
REQUIREMENTS AND CONFIGURATION

OCTOBER 8, 1985

CARL B. SHELLEY
MANAGER, CUSTOMER INTEGRATION OFFICE
SPACE STATION PROGRAM OFFICE
JOHNSON SPACE CENTER
FTS 525-4095

S-85-01852

Space Station Complex Early 1990



NASA

S-85-01859

What Is Space Station?

- THE NEXT STEP IN PROVIDING THE NATION WITH AN EXPANDED CAPABILITY TO ACCESS THE SPACE ENVIRONMENT
- IT IS:
  - A SCIENTIFIC AND TECHNOLOGY RESEARCH LABORATORY
  - A PERMANENT OBSERVATORY
  - A PAYLOAD/SPACECRAFT SERVICING FACILITY
  - A LARGE STRUCTURE CONSTRUCTION AND ASSEMBLY FACILITY
  - A MANUFACTURING FACILITY
  - A TRANSPORTATION MODE
  - A STAGING BASE FOR FUTURE ENDEAVORS IN SPACE

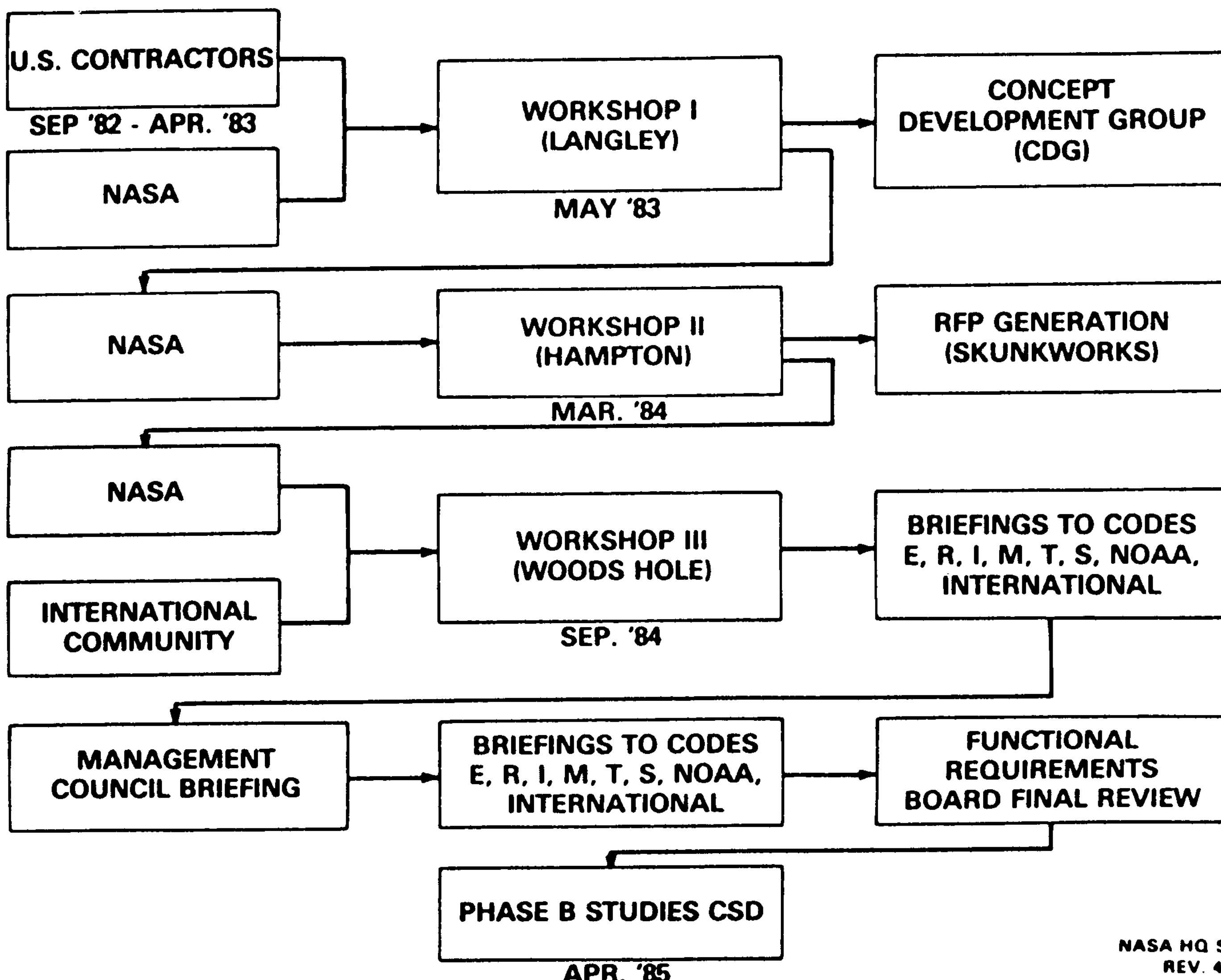
S-85-01856

Space Station Characteristics

- CONTINUOUSLY HABITABLE
- SHUTTLE DEPENDENT
- MANNED AND UNMANNED ELEMENTS
- MAINTAINABLE/RESTORABLE
- OPERATIONALLY SEMI-AUTONOMOUS
- TECHNOLOGY TRANSPARENT
- EVOLUTIONARY
- USER FRIENDLY

SPACE STATION PROGRAM

REVIEWS OF USER/CUSTOMER REQUIREMENTS



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REV. 4-2-85
(OSSTT 39F)

STATUS OF DATA BASE

- THERE ARE NOW OVER 300 "MISSIONS" IN THE DATA BASE
  - variability in missions from individual instruments with discrete operational periods to full modules present for life of Space Station
- EACH MISSION IS REPRESENTED BY 516 PARAMETERS
  - parameters are time phased and include functions (i.e., average and peak power), and location
- THE DATA BASE CONTAINS A NUMBER OF REPLICATE OR SIMILAR MISSIONS FROM DIFFERENT SPONSORS
- SPONSORS ARE:
  - NASA
  - NOAA
  - Canada
  - ESA
  - Japan
  - Commercial Community
- THERE ARE NO ENTRIES FROM THE DOD

USER CHARACTERISTICS

- MAJOR USER TYPES ON MANNED ELEMENT ARE:
  - Servicing, assembly, and transportation node
  - Materials production, research, and development
  - Life sciences
  - Technology development
  - Others include solar physics, plasma physics, astrophysics, atmospheric physics
- MAJOR USERS ON POLAR PLATFORM ARE EARTH OBSERVATIONS WITH SOME PLASMA PHYSICS
  - Research
  - Operational
- ONLY SMALL DEMAND FOR CO-ORBITING PLATFORM BUT MAY GROW

DSG-1480

NASA
S-85-01853

Types of Anticipated Usage By Sponsor

DISCIPLINE	CANADA	ESA	JAPAN	NOAA	NASA OAST	NASA OCP	NASA OSSA
ASTRONOMY	●	●	●				●
- PLANETARY							
- STELLAR							
- SOLAR PHYSICS							
- ASTROPHYSICS							
EARTH OBSERVATIONS	●	●	●	●			●
- LAND							
- ATMOSPHERE							
- OCEAN							
- ICE							
LIFE SCIENCES	●	●	●				●
MATERIALS RESEARCH AND DEVELOPMENT	●	●	●		●	●	●
MATERIALS PRODUCTION		●				●	●
GENERAL COMMERCIAL						●	
PLASMA PHYSICS	●		●				●
TECHNOLOGY DEVELOPMENT AND DEMONSTRATION	●	●	●		●		
ASSEMBLY, SERVICING AND STAGING	●	●	●	●	●	●	●

NASA

S-85-00737

Distribution of Space Station Missions

	MANNED ELEMENT	CO-ORBIT PLATFORM	POLAR PLATFORM	FREE FLYERS	TOTAL
• U.S.	156	0	58	28	242
• ESA	9	3	5	0	17
• JAPAN	22	0	3	15	40
• CANADA	13	1	6	2	22
TOTAL	200	4	72	45	321

SPACE STATION MISSION REQUIREMENTS

TYPE OF MISSION*	NUMBER OF MISSIONS			
	U.S.	CANADA	EUROPE	JAPAN
SCIENCE APPLICATIONS OPERATIONAL	108	7	22	17
TECHNOLOGY	70	11	5	21
COMMERCIAL	59	4	—	—
TOTAL	237	22	27	38

EFFORT IN NEXT SEVERAL MONTHS WILL BE TO SELECT FROM THESE CANDIDATE MISSIONS THE BEST SET FROM WHICH TO DERIVE SPACE STATION ACCOMODATIONS

* A "MISSION" RANGES FROM A COMPLETE MANNED MODULE TO AN INDIVIDUAL INSTRUMENT/EXPERIMENT

FILE NAME: S/SpaStaReq

NASA HQ S Rev. 1-17-85
OSSTT 121

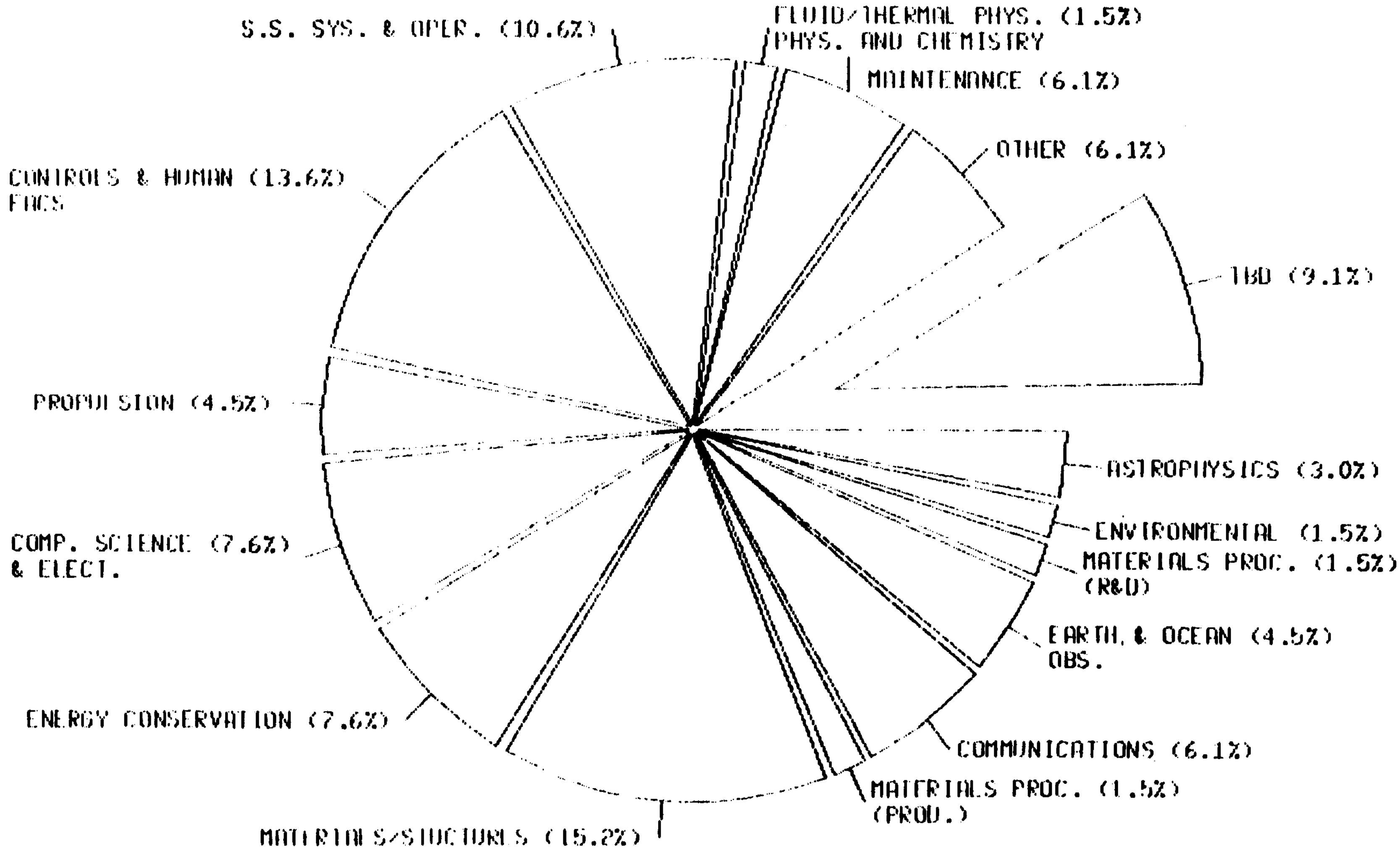
TECHNOLOGY DEVELOPMENT

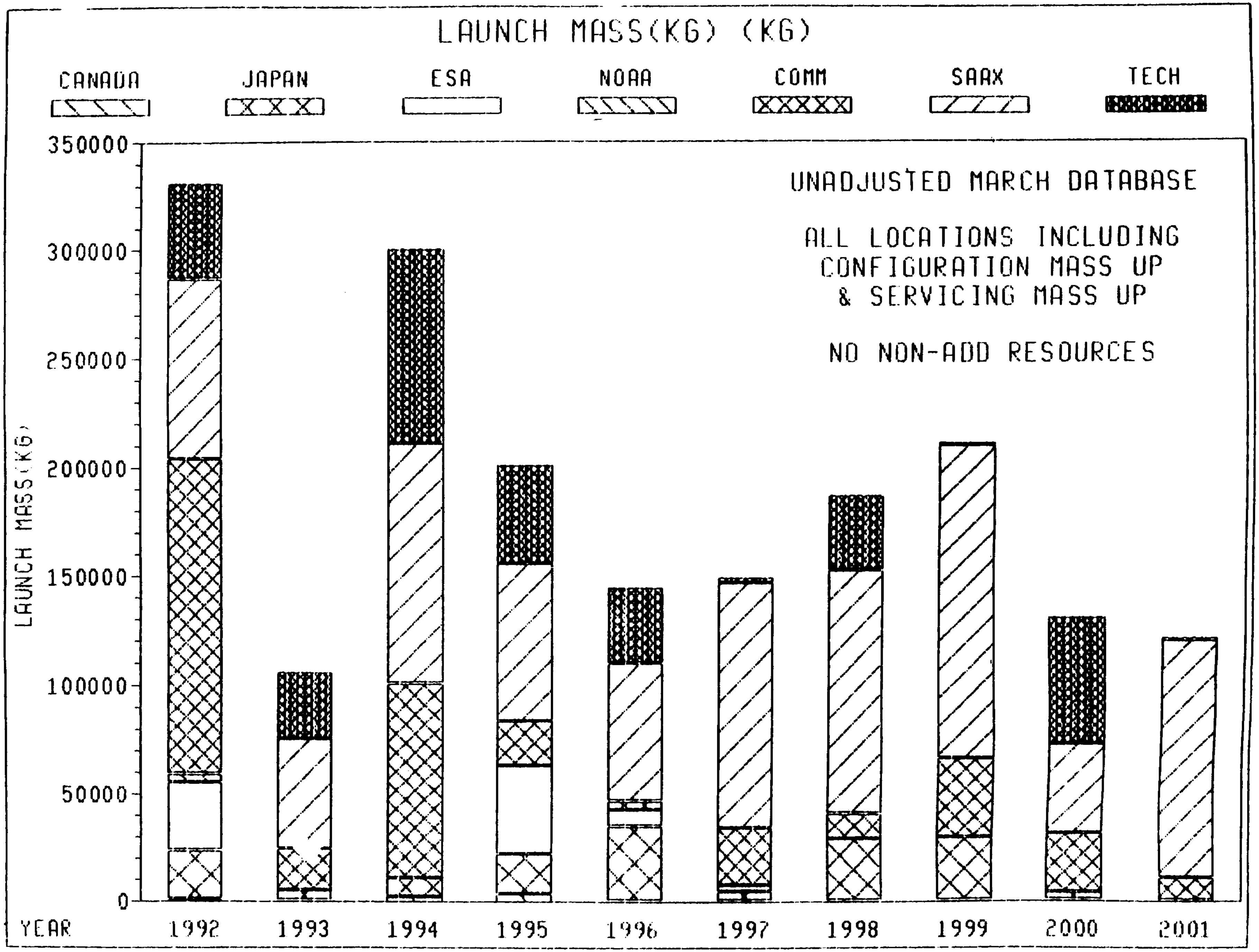
- DERIVED FROM GRASSROOTS INPUTS FROM NASA CENTERS AND MISSION ANALYSIS STUDY (MAS) CONTRACTORS
- PRELIMINARY NASA OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY ASSESSMENT COMPLETED
  - Acceptable range of experimental opportunities represented
  - Missing technical areas identified
  - Experiment definition initiated at ARC, LaRC, and LeRC
- DETAILED LaRC ASSESSMENT FOR NASA OFFICE OF AERONAUTICS AND SPACE TECHNOLOGY COMPLETED
  - Entries screened
  - Missing technical areas identified

OSS-80

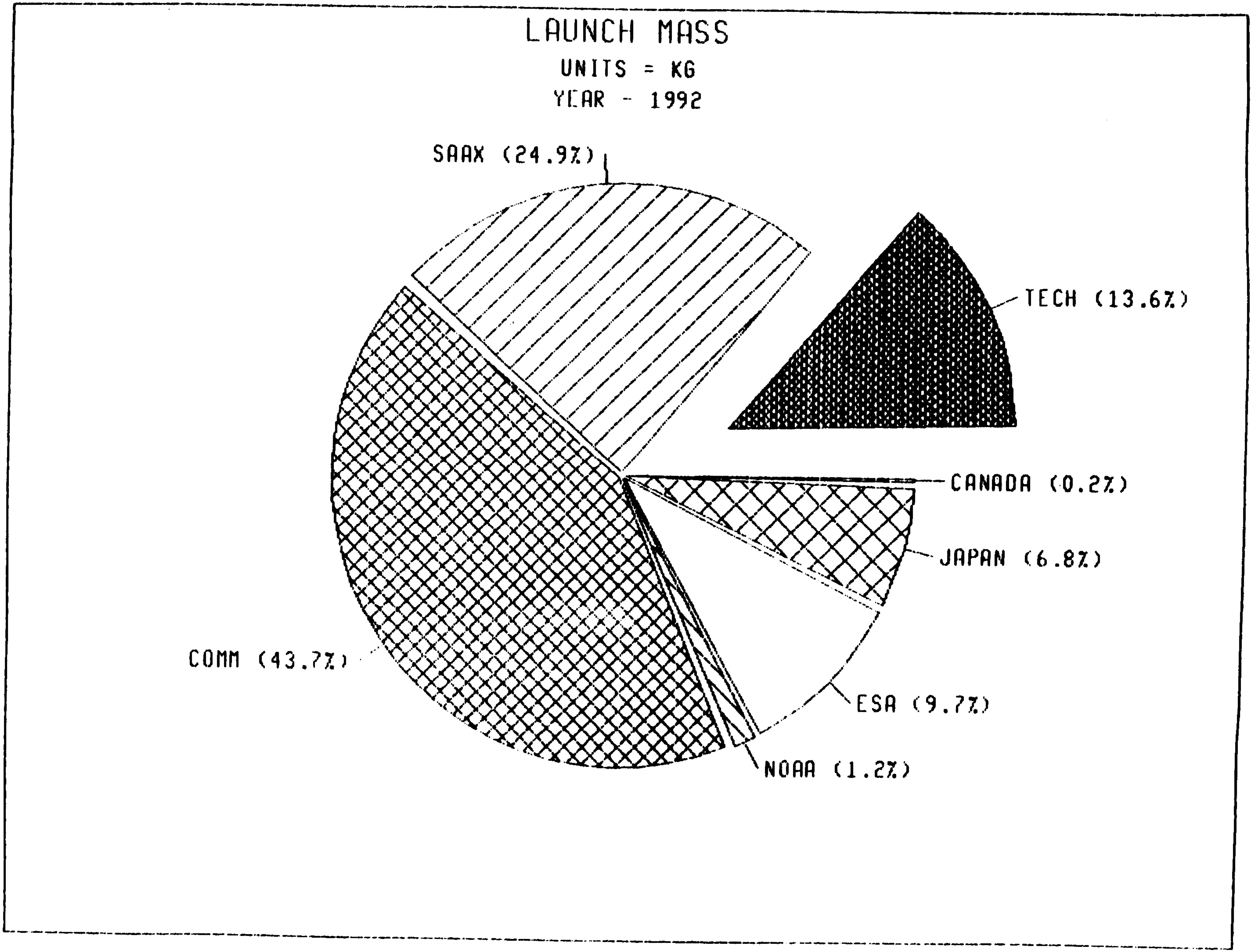
TDMX

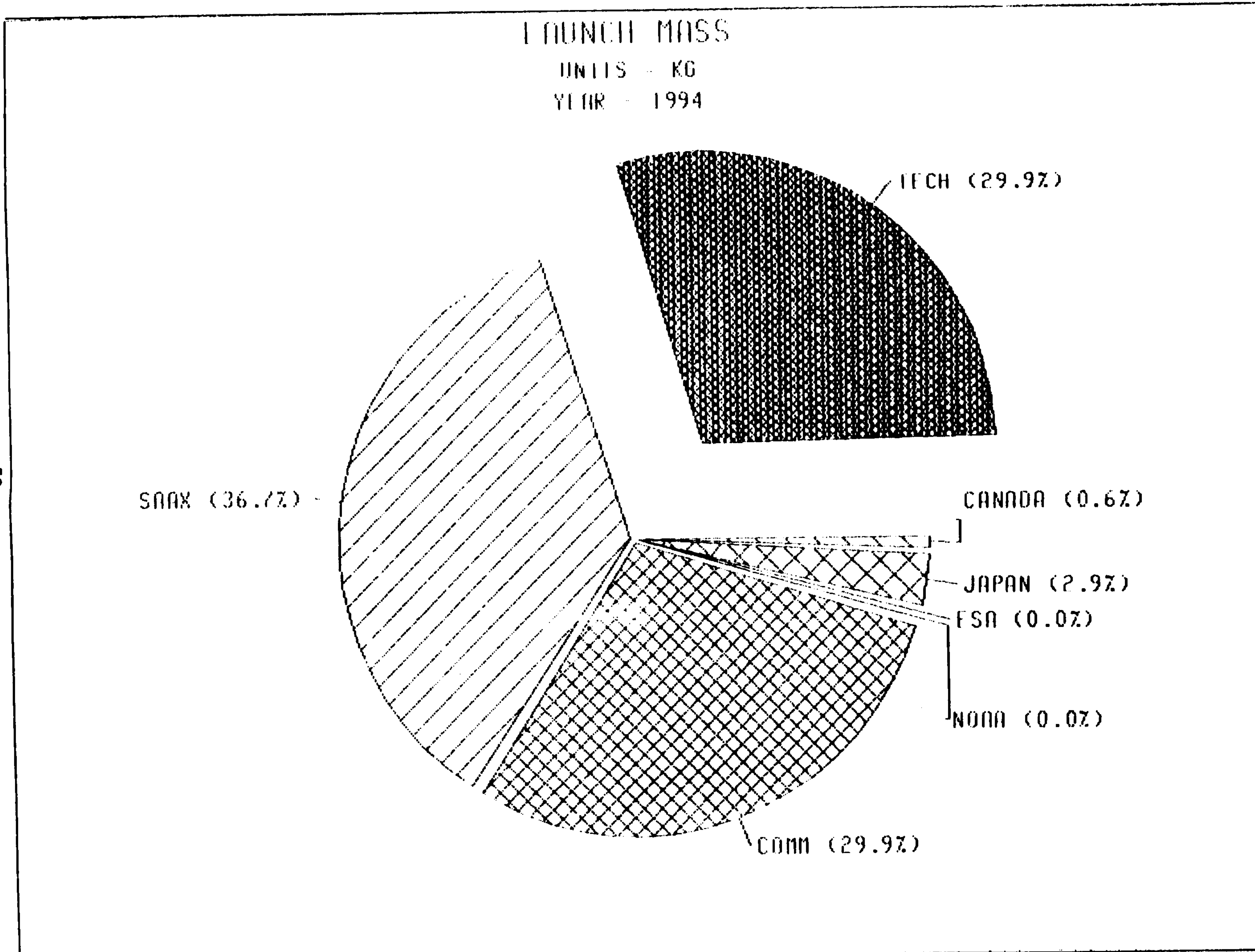
TYPE NUMBER

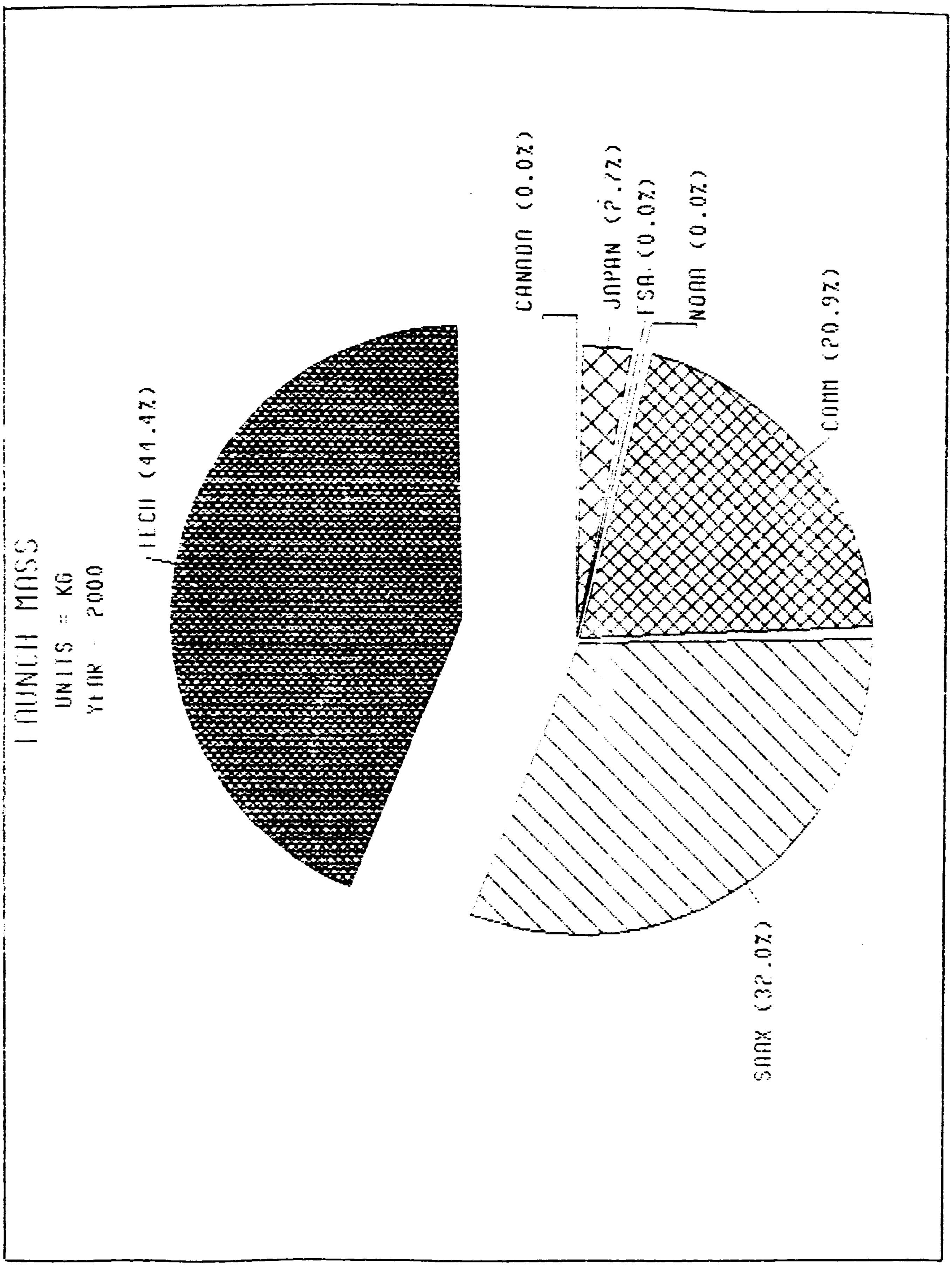


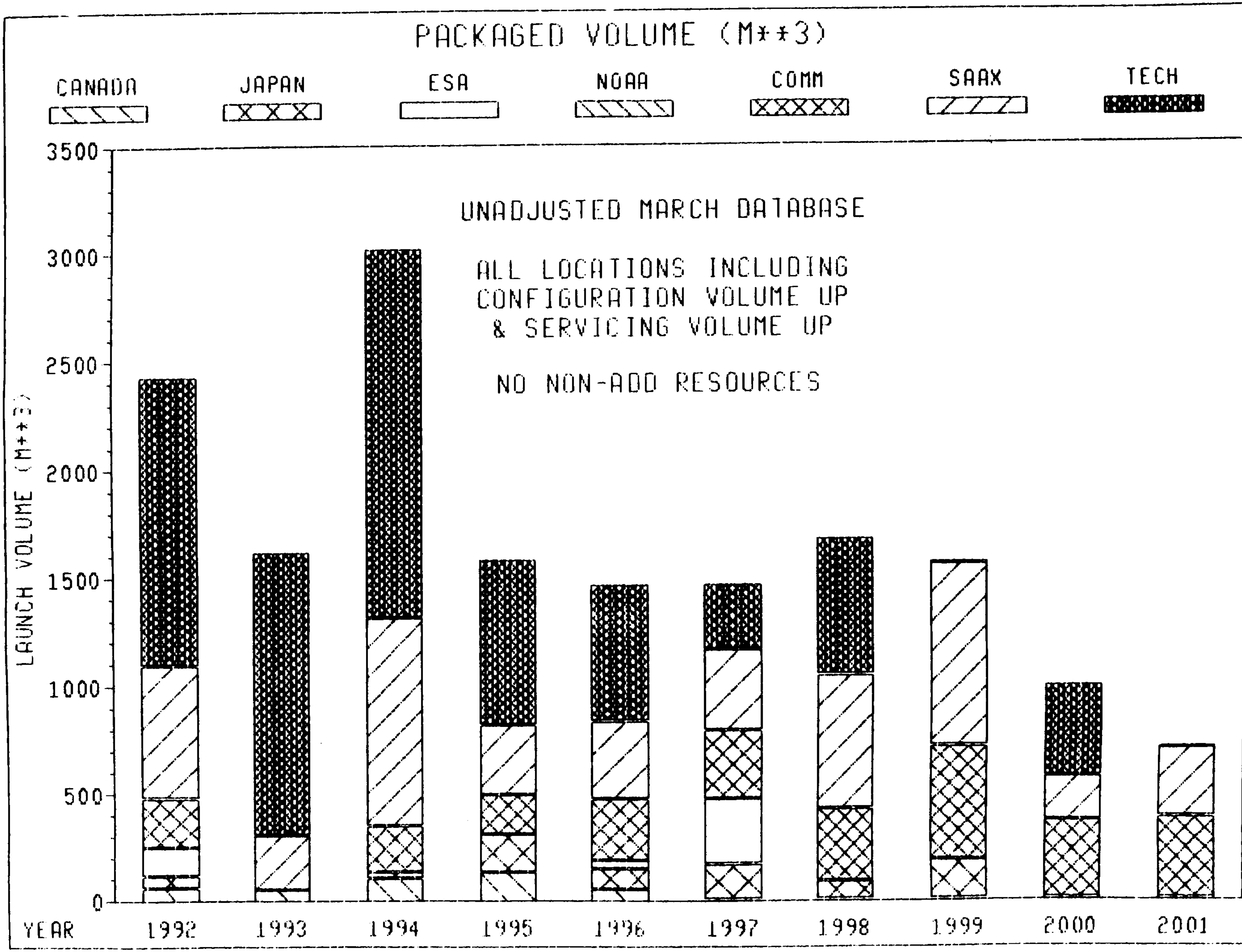


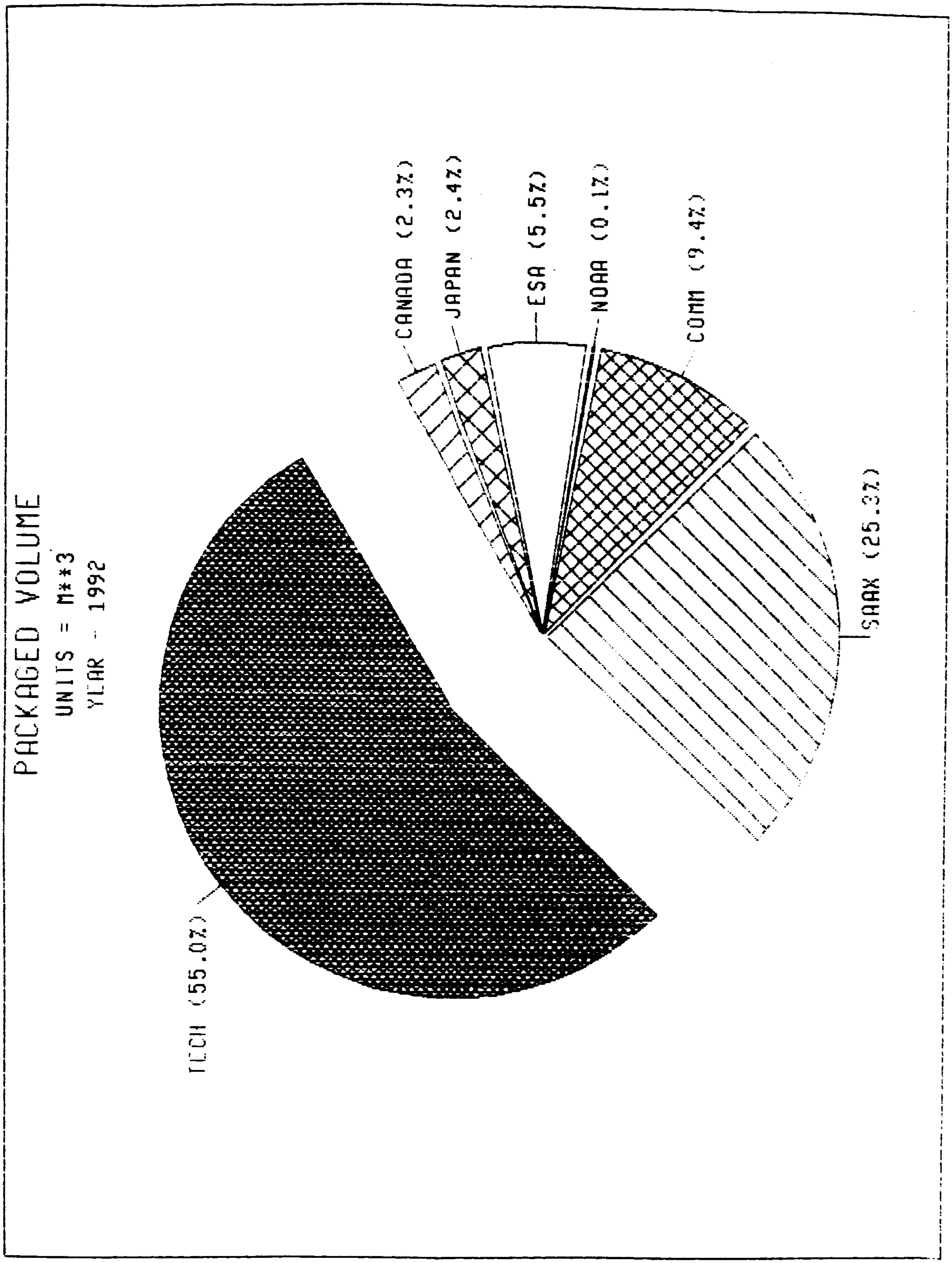
LAUNCH MASS(KG) (KG)
CANADA
JAPAN
ESA
NOAA
COMM
SAAX
TECH
UNADJUSTED MARCH DATABASE
ALL LOCATIONS INCLUDING
CONFIGURATION MASS UP
& SERVICING MASS UP
NO NON-ADD RESOURCES
LAUNCH MASS(KG)
350000
300000
250000
200000
150000
100000
50000
0
YEAR
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

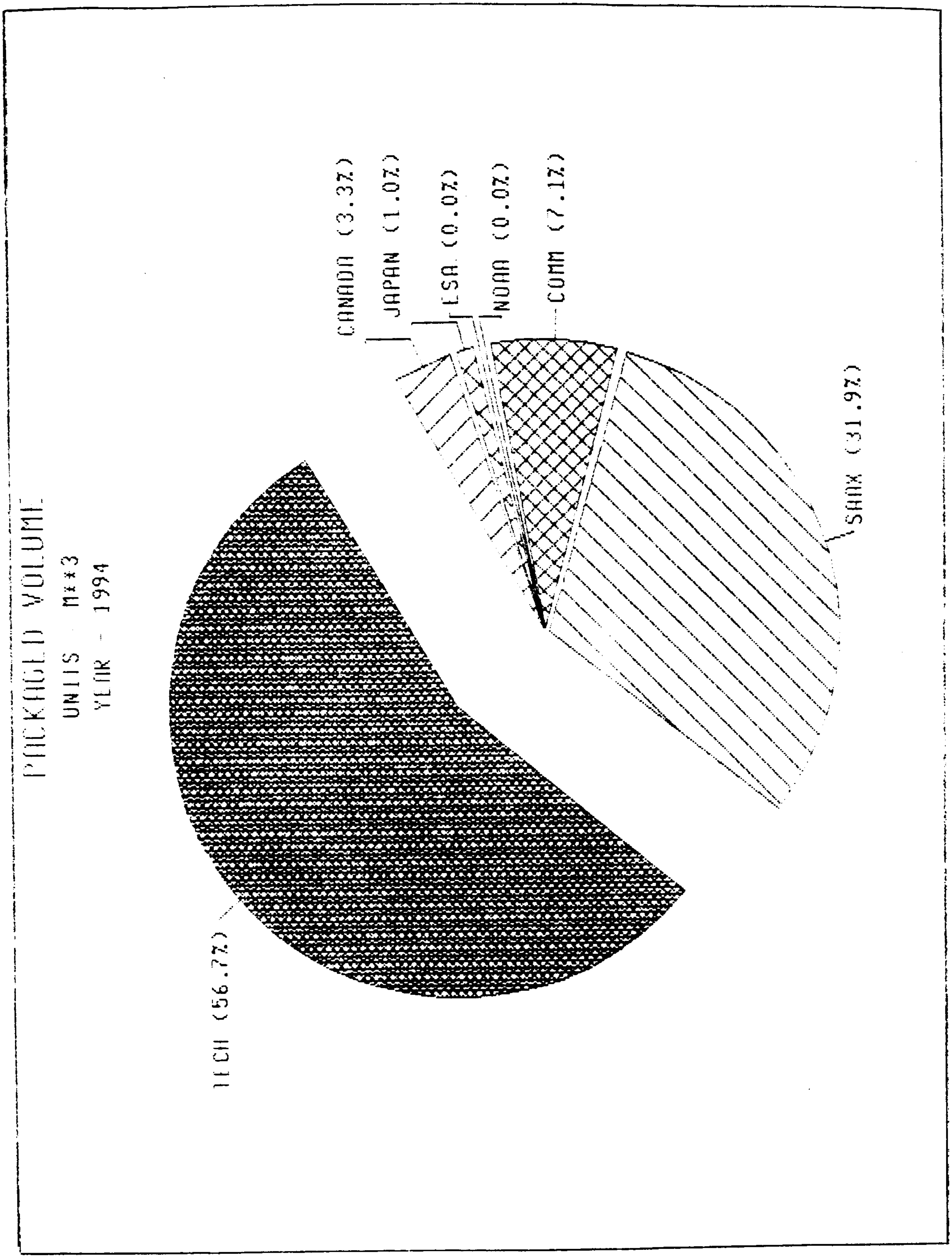

LAUNCH MASS
UNITS = KG
YEAR - 1992
SAAX (24.9%)
TECH (13.6%)
CANADA (0.2%)
JAPAN (6.8%)
ESA (9.7%)
NOAA (1.2%)
COMM (43.7%)

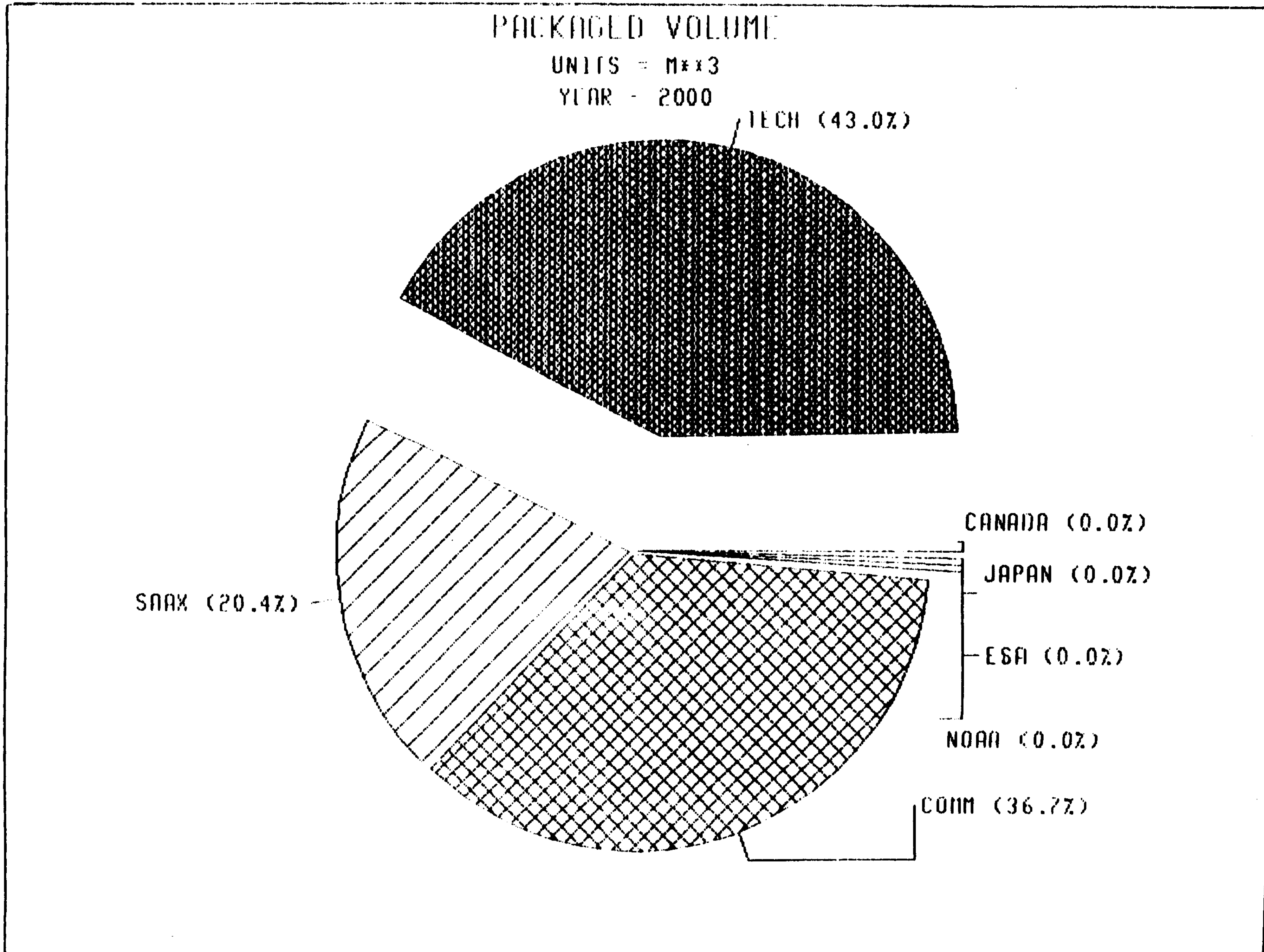

LAUNCH MASS
UNITS - KG
YEAR - 1994
TECH (29.9%)
CANADA (0.6%)
JAPAN (2.9%)
ESA (0.0%)
NOAA (0.0%)
COMM (29.9%)
SAAX (36.7%)

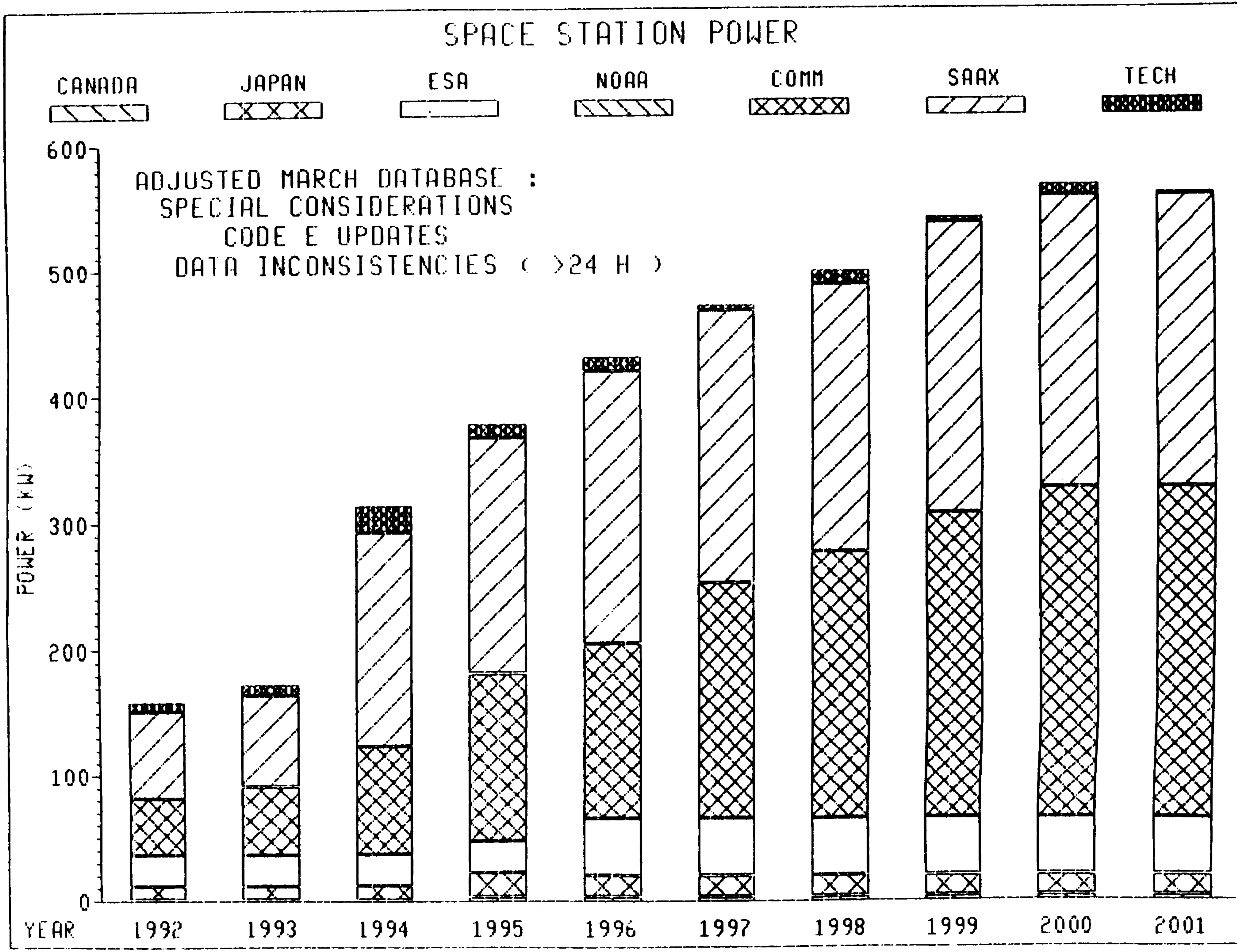

LAUNCH MASS
UNITS = KG
YEAR = 2000
TECH (44.4%)
CANADA (0.0%)
JAPAN (2.7%)
ESA (0.0%)
NOAA (0.0%)
COMM (20.9%)
SAAX (32.0%)

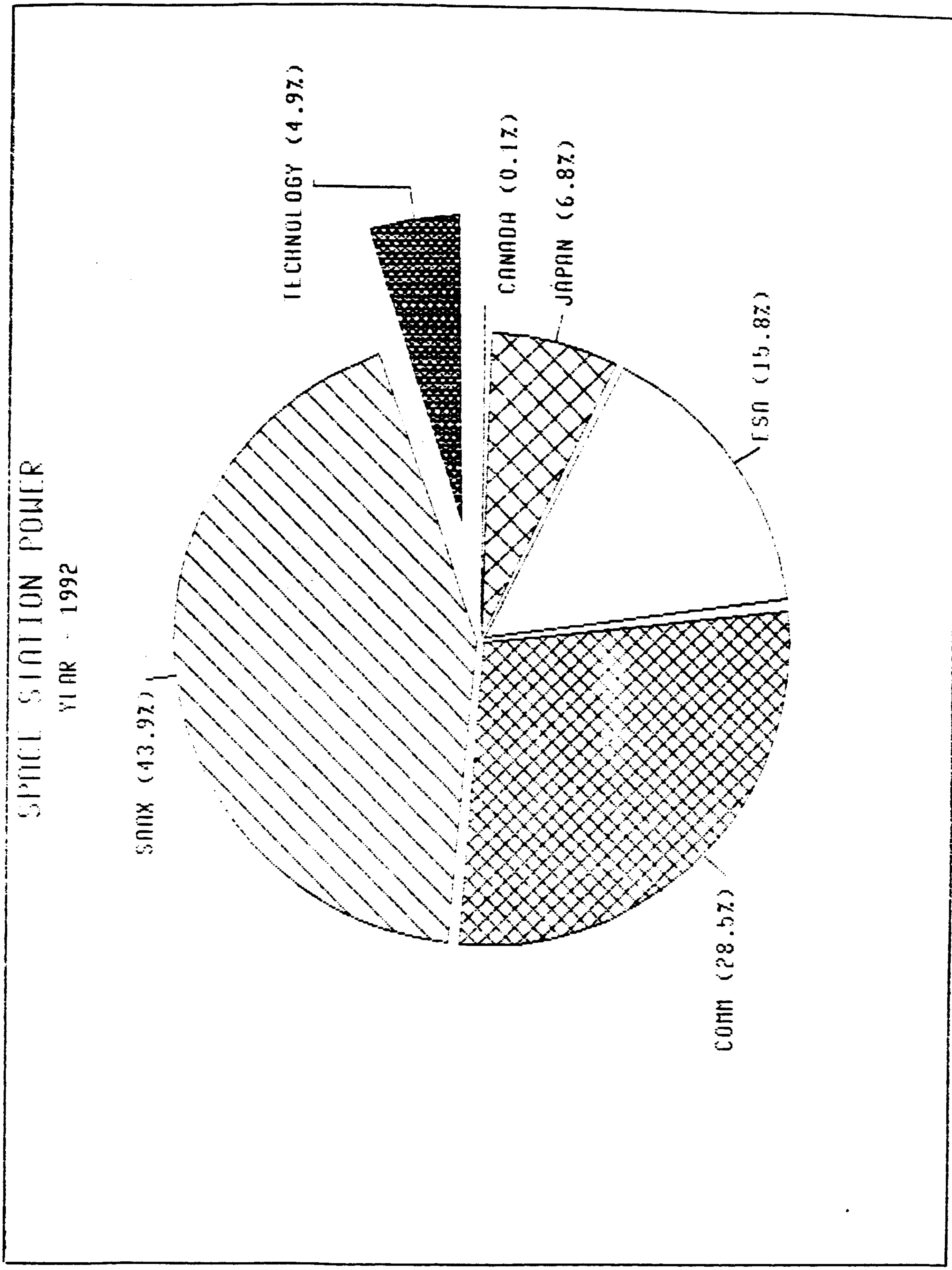

PACKAGED VOLUME (M**3)
CANADA
JAPAN
ESA
NOAA
COMM
SAAX
TECH
UNADJUSTED MARCH DATABASE
ALL LOCATIONS INCLUDING
CONFIGURATION VOLUME UP
& SERVICING VOLUME UP
NO NON-ADD RESOURCES
LAUNCH VOLUME (M**3)
3500
3000
2500
2000
1500
1000
500
0
YEAR
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

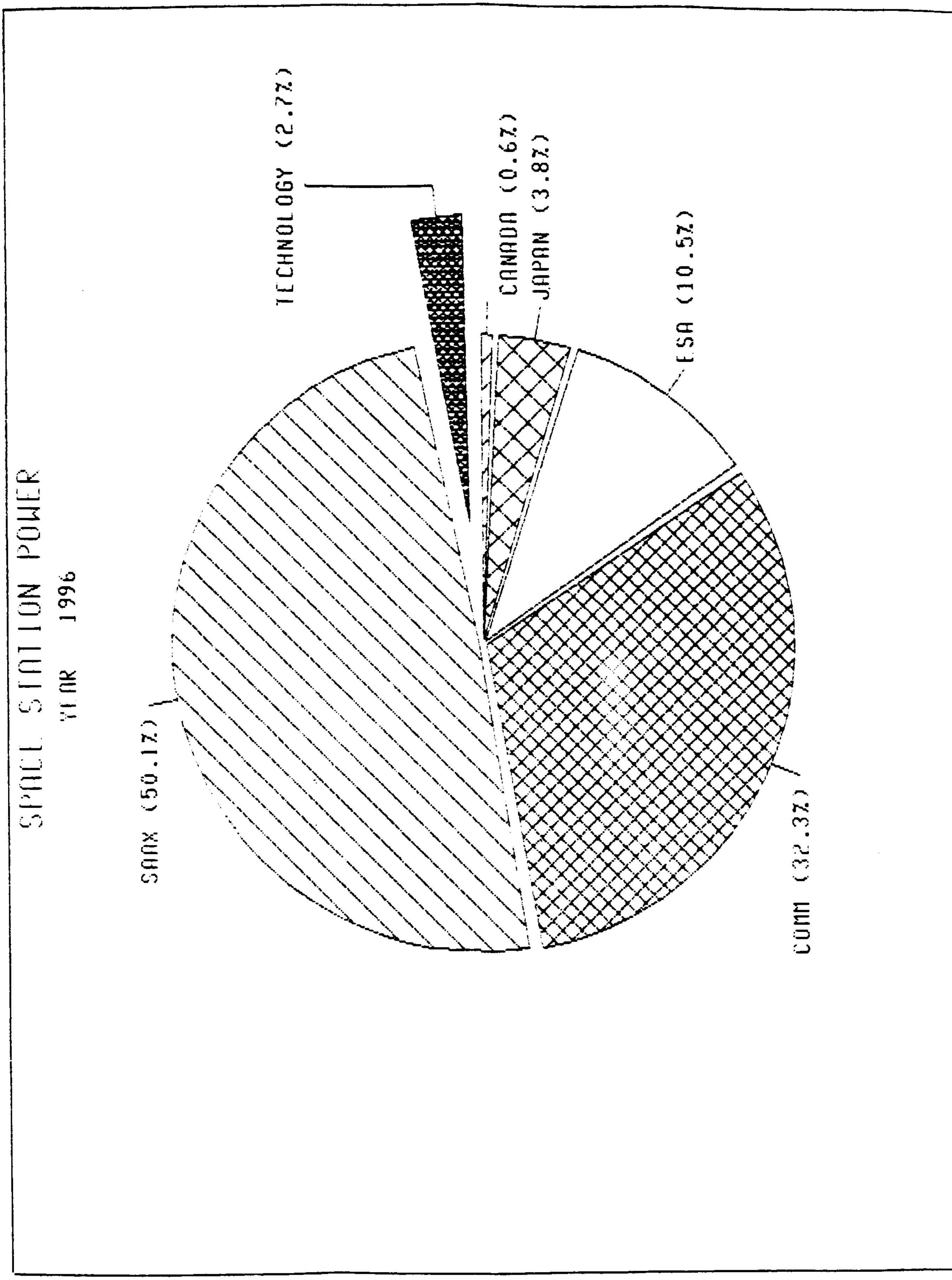

PACKAGED VOLUME
UNITS = M**3
YEAR - 1992
CANADA (2.3%)
JAPAN (2.4%)
ESA (5.5%)
NOAA (0.1%)
COMM (9.4%)
SAAX (25.3%)
TECH (55.0%)


PACKAGED VOLUME
UNITS - M**3
YEAR - 1994
CANADA (3.3%)
JAPAN (1.0%)
ESA (0.0%)
NOAA (0.0%)
COMM (7.1%)
SAMX (31.9%)
TECH (56.7%)


PACKAGED VOLUME
UNITS = M**3
YEAR - 2000
TECH (43.0%)
CANADA (0.0%)
JAPAN (0.0%)
ESA (0.0%)
NOAA (0.0%)
COMM (36.7%)
SAAX (20.4%)

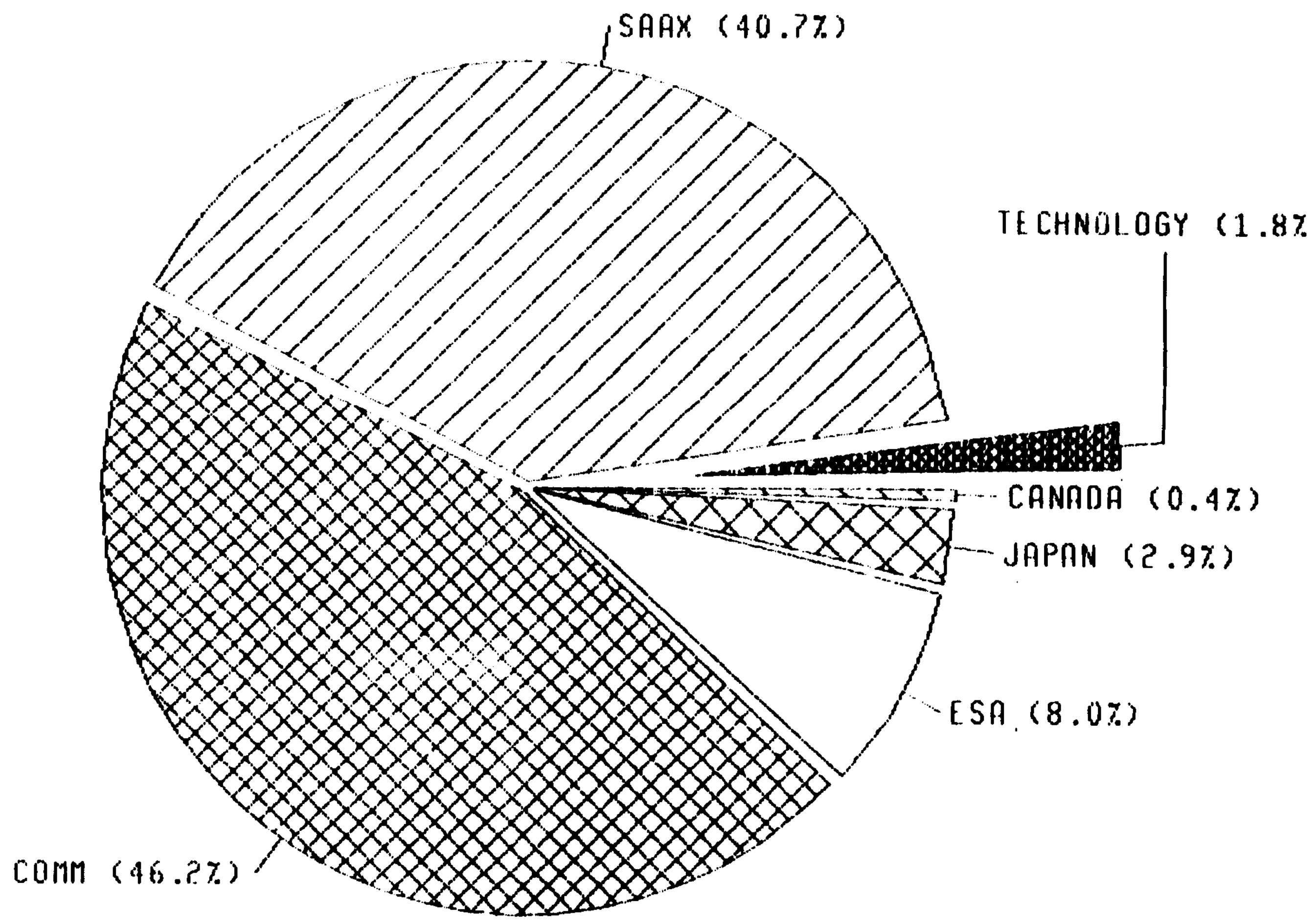

SPACE STATION POWER
CANADA
JAPAN
ESA
NOAA
COMM
SAAX
TECH
ADJUSTED MARCH DATABASE :
SPECIAL CONSIDERATIONS
CODE E UPDATES
DATA INCONSISTENCIES (>24 H)
POWER (KW)
600
500
400
300
200
100
0
YEAR
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

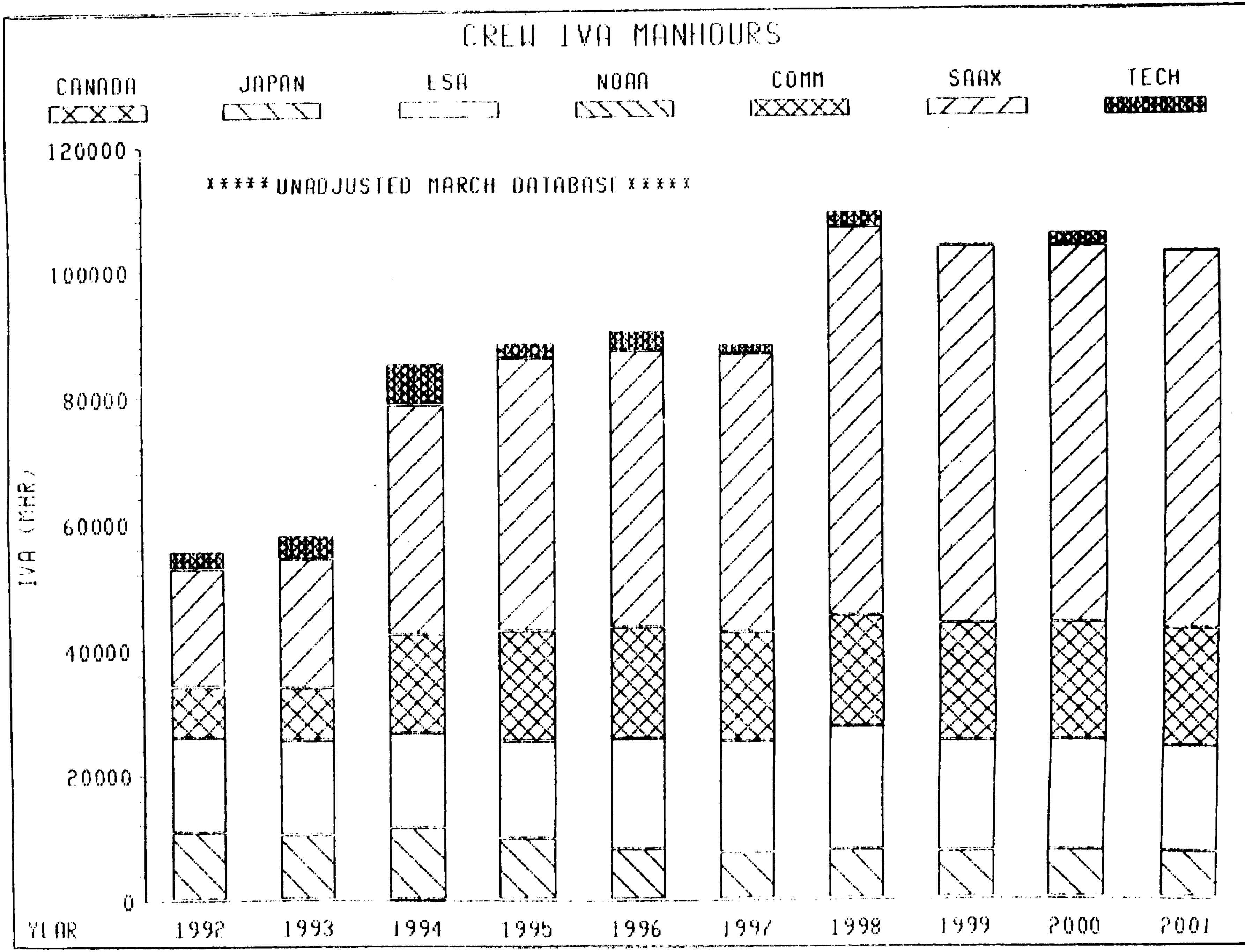

SPACE STATION POWER
YEAR - 1992
TECHNOLOGY (4.9%)
CANADA (0.1%)
JAPAN (6.8%)
ESA (15.8%)
COMM (28.5%)
SAAX (43.9%)


SPACE STATION POWER
YEAR 1996
TECHNOLOGY (2.7%)
CANADA (0.6%)
JAPAN (3.8%)
ESA (10.5%)
COMM (32.3%)
SAAX (50.1%)

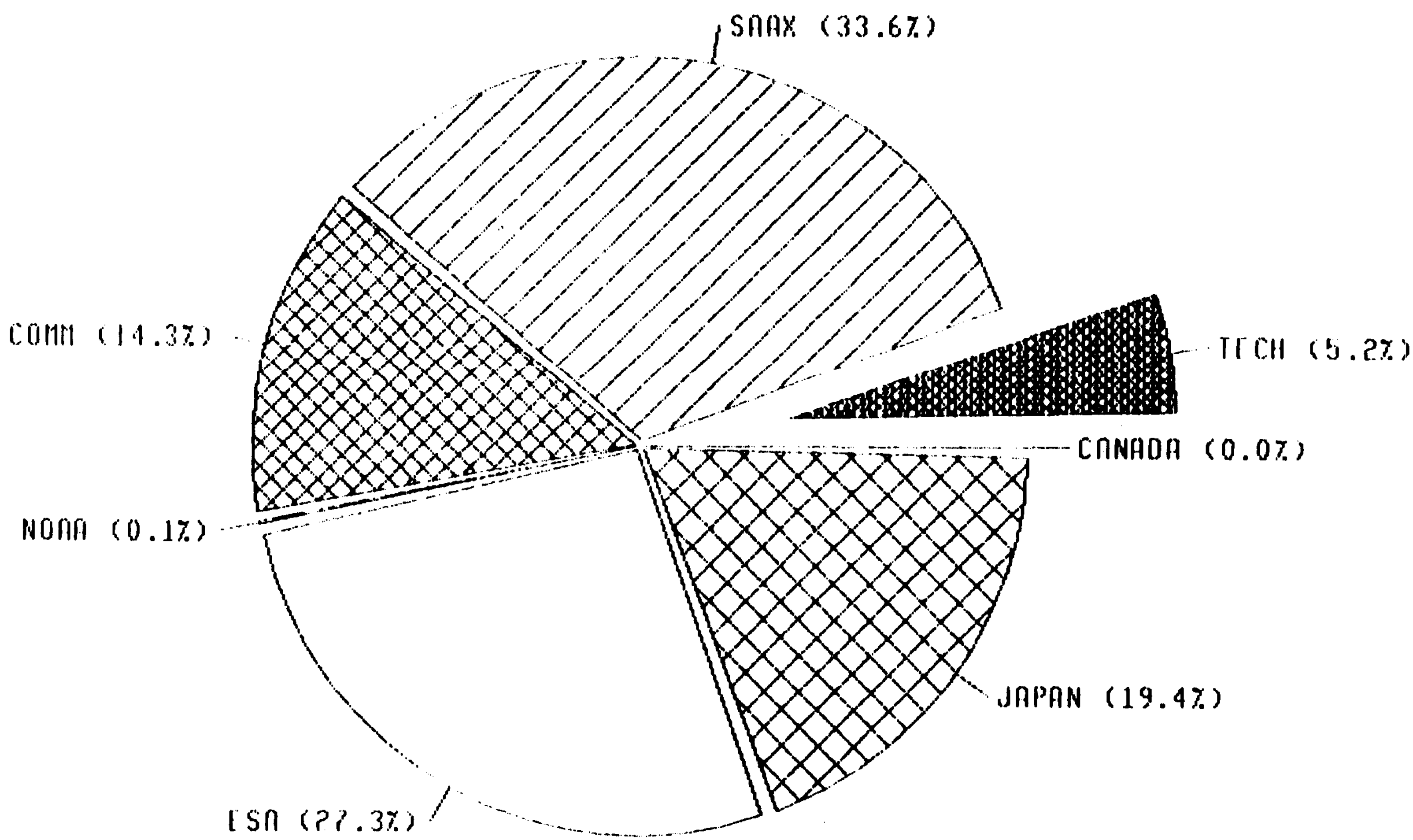
SPACE STATION POWER

YEAR - 2000



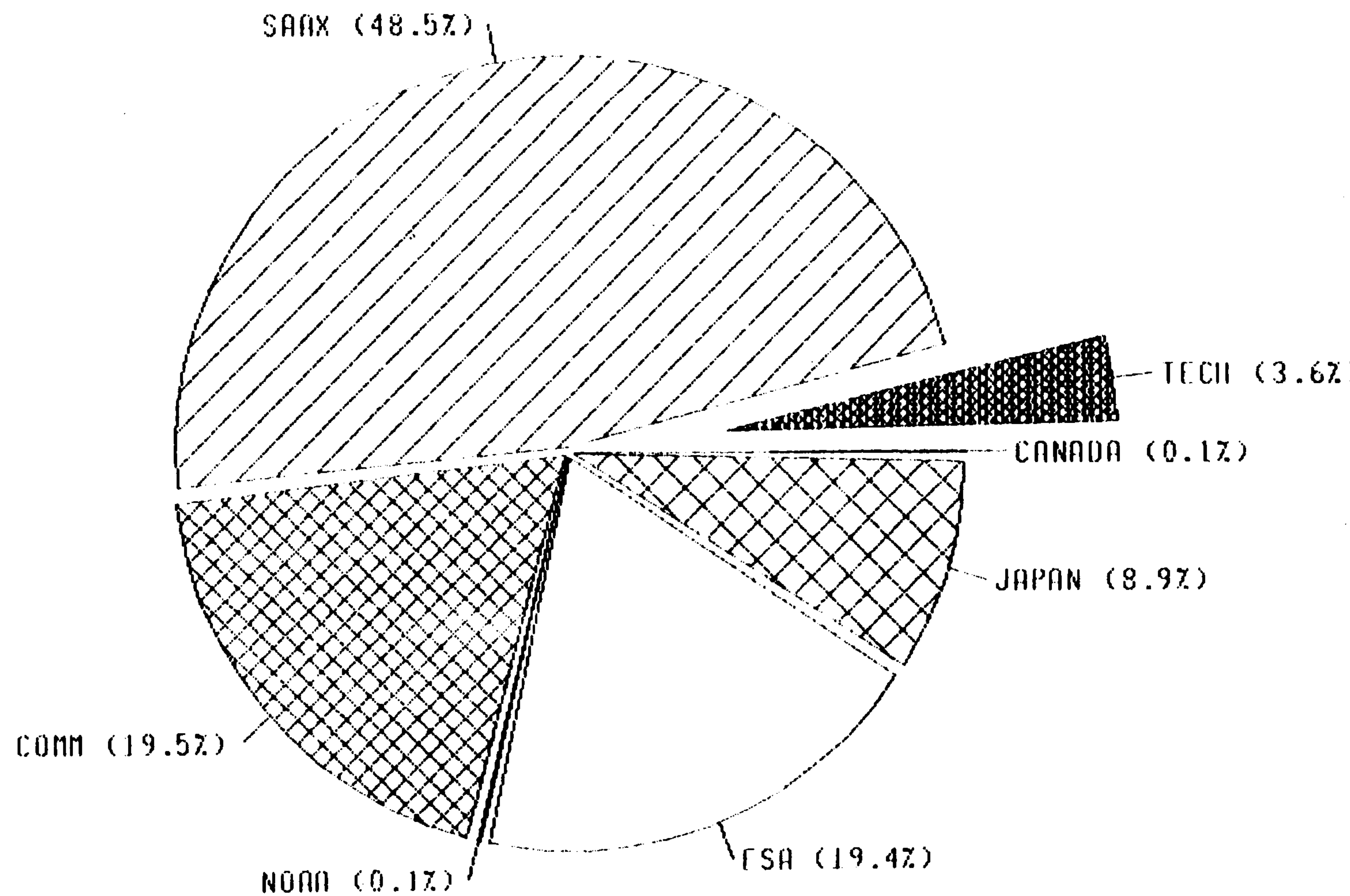

CREW IVA MANHOURS
CANADA
JAPAN
ESA
NOAA
COMM
SAAX
TECH
120000
100000
80000
60000
40000
20000
0
*****UNADJUSTED MARCH DATABASE*****
IVA (MHR)
YEAR
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

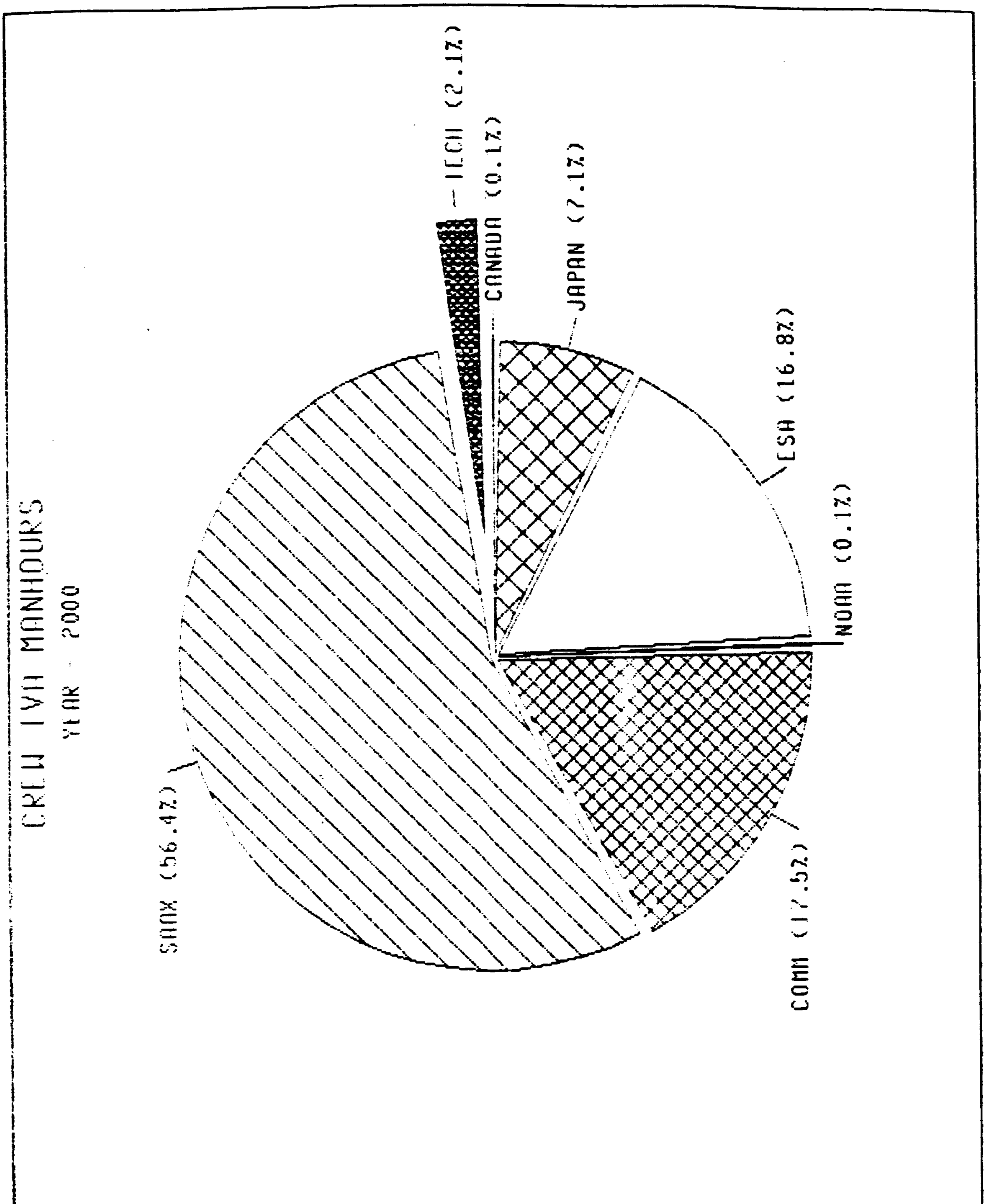
CREW IVA MANHOURS
YEAR - 1992



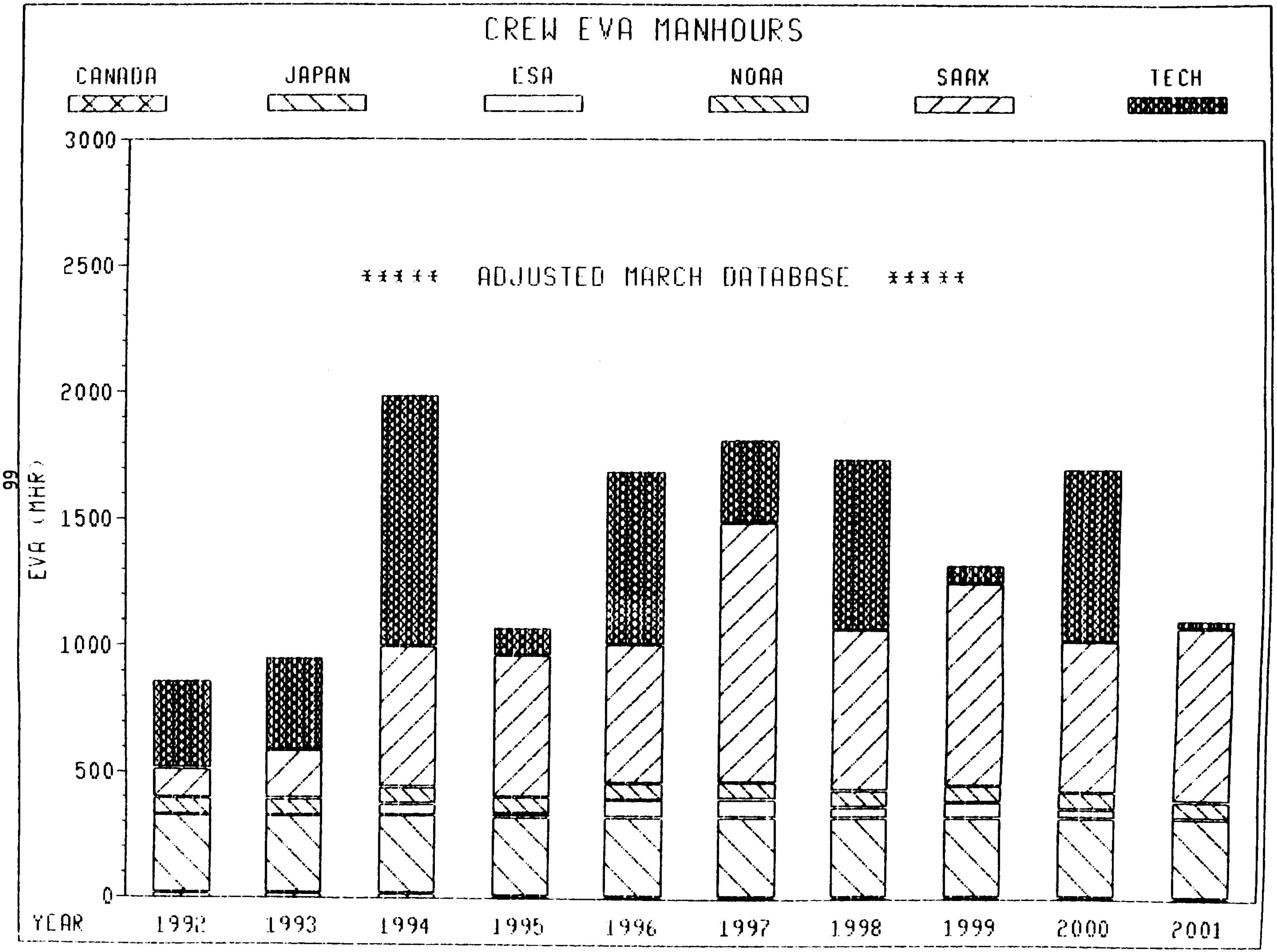
CREW IVA MANHOURS

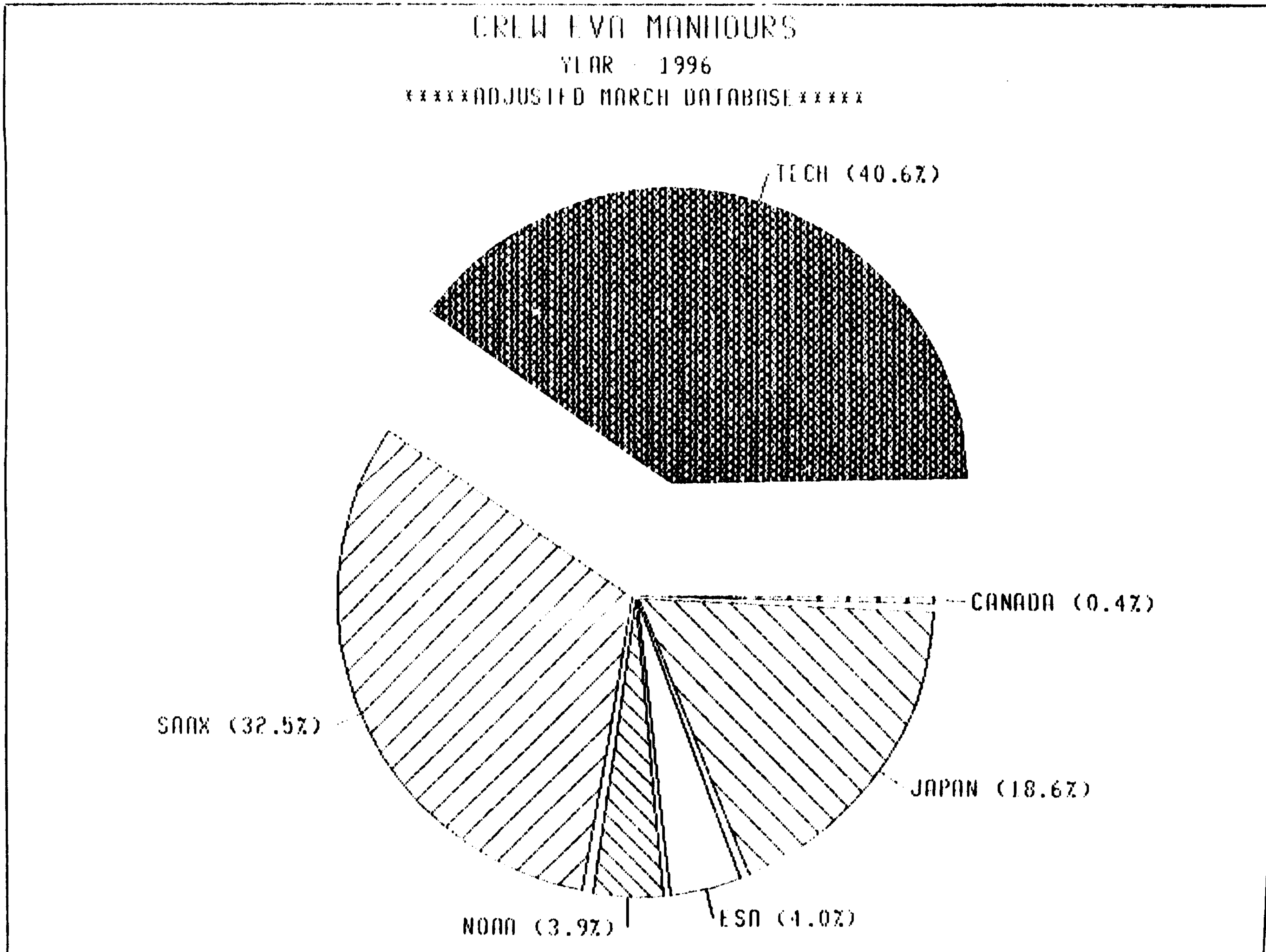
YEAR - 1996

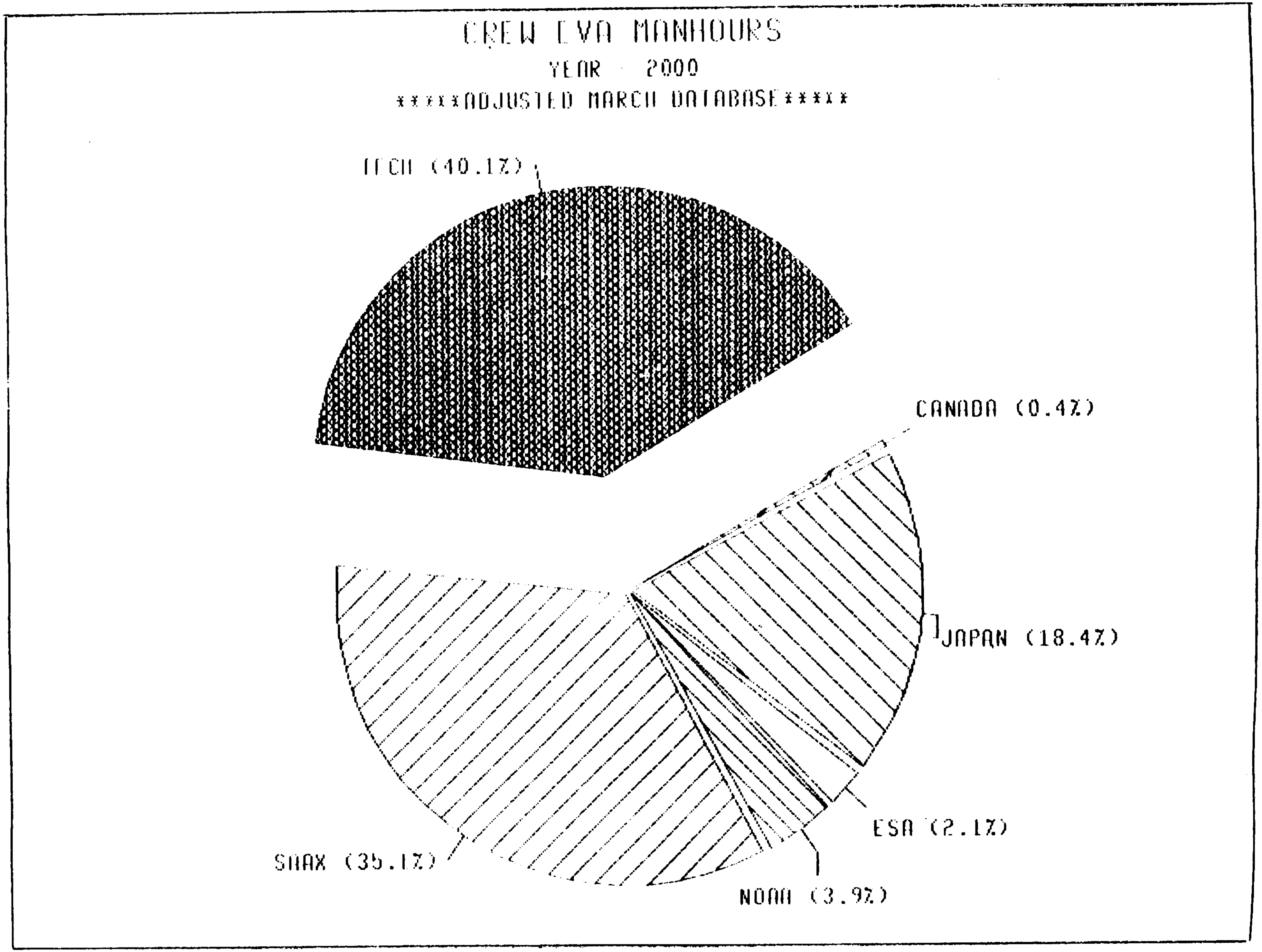




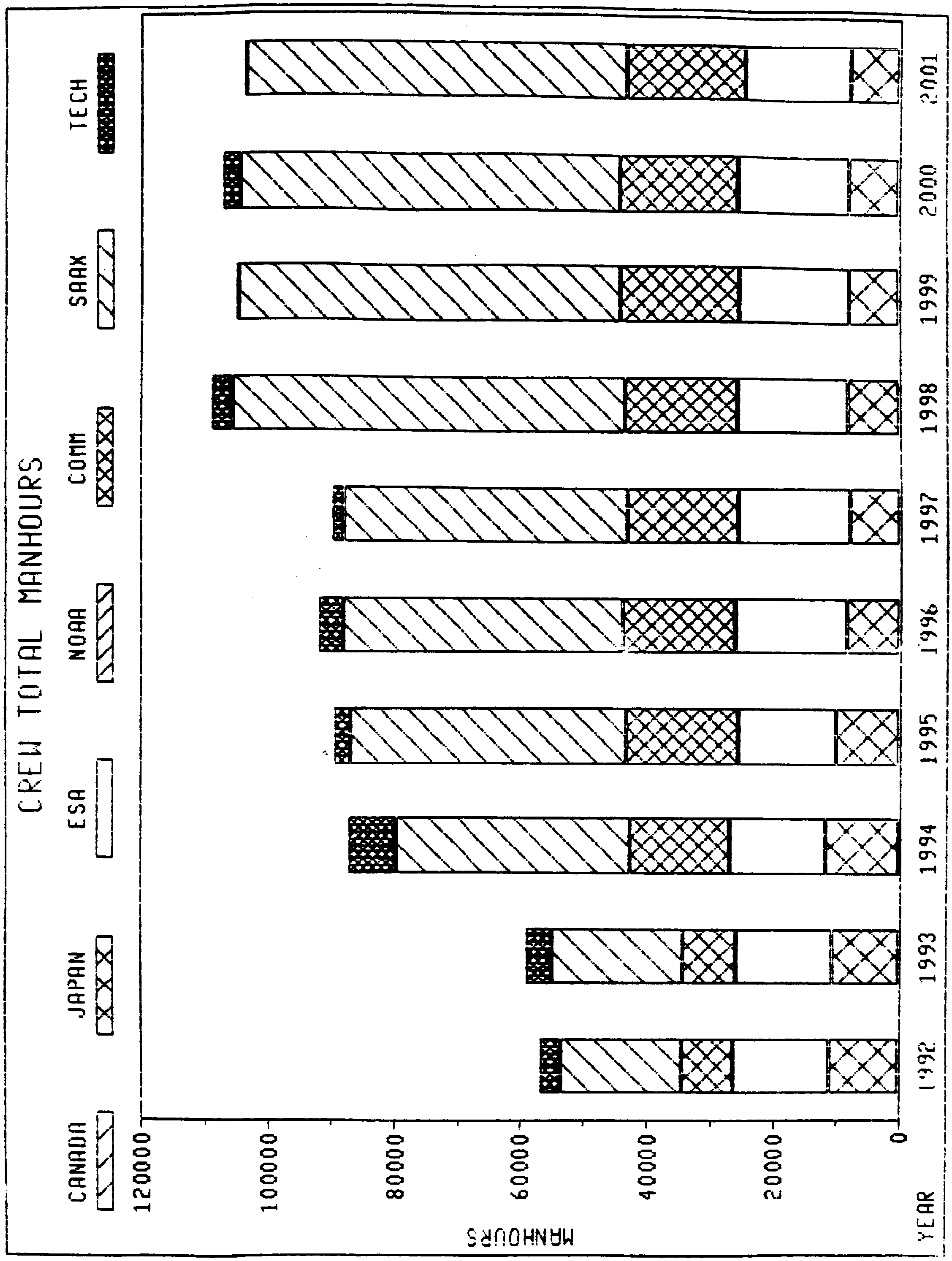
CREW IVA MANHOURS
YEAR - 2000
TECH (2.1%)
CANADA (0.1%)
JAPAN (7.1%)
ESA (16.8%)
NOAA (0.1%)
COMM (17.5%)
SAAX (56.4%)


CREW EVA MANHOURS
CANADA
JAPAN
ESA
NOAA
SAAX
TECH
3000
2500
2000
1500
1000
500
0
***** ADJUSTED MARCH DATABASE *****
EVA (MHR)
YEAR
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001


CREW EVA MANHOURS
YEAR 1996
*****ADJUSTED MARCH DATABASE*****
TECH (40.6%)
CANADA (0.4%)
SAAX (32.5%)
JAPAN (18.6%)
NOAA (3.9%)
ESA (4.0%)



CREW EVA MANHOURS
YEAR 2000
*****ADJUSTED MARCH DATABASE*****
TECH (40.1%)
CANADA (0.4%)
JAPAN (18.4%)
ESA (2.1%)
NOAA (3.9%)
SMAX (35.1%)


CREW TOTAL MANHOURS
CANADA
JAPAN
ESA
NOAA
COMM
SAAX
TECH
MANHOURS
120000
100000
80000
60000
40000
20000
0
YEAR
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001

NASA
S-85-01862

Functional Requirements Envelope
Manned Element - Users Only[1]

	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
STS LAUNCHES[2]	4	6	9	12	12	13	14	14	11	9
AVERAGE ELECTRICAL POWER (KW)	80	85	155	245	290	290	340	375	375	375
AVERAGE DATA RATE TO GROUND (MBPS)	20	75	140	160	165	145	165	145	160	135
PRESSURIZED VOLUME (M^3)[3]	120	125	200	270	295	300	325	325	325	330
USER CREW[4]	10	11	14	17	18	18	17	18	20	20
EVA HOURS[5]	412	368	462	509	810	915	1504	780	820	794
NUMBER OF ATTACHED PAYLOADS	14	15	12	13	15	18	15	14	15	13
OMV EVENTS[6]	6	12	24	24+	24+	24+	24+	24+	24+	24+

NASA

S-85-01863

Functional Requirements Envelope
Manned Element - User Only

1) ALL PARAMETERS ARE FOR RESOURCES AVAILABLE TO THE USER AND DO NOT INCLUDE "OVERHEAD"

2) IN ADDITION TO USE OF 6000KG PAYLOAD ALLOCATION ON EACH OF FOUR LOGISTICS MODULES A YEAR. ASSUMES LAUNCHES OF 15000KG CAPABILITY DEDICATED TO PAYLOADS. DOES NOT INCLUDE OVERHEAD SUCH AS LAUNCH OF ADDITIONAL MODULES, OMV FUEL, ETC.

3) MULTI-USER LABORATORY VOLUME REQUIRED FOR USERS' INSTRUMENTATION. DOES NOT INCLUDE HABITATION VOLUME OR PRIVATELY SUPPLIED VOLUME DEDICATED TO A SINGLE USER

4) ASSUMES 9 HOUR WORK DAY AND SIX DAY WEEK. ASSUMES USER CREW WILL PERFORM PAYLOAD ASSOCIATED EVA AND RMS AND OMV PROXIMITY OPERATIONS

5) PRODUCTIVE EVA WORK HOURS. NOT ADDITIVE. CREW REQUIRED TO PERFORM EVA INCLUDED IN "USER CREW" TOTALS

6) NUMBER OF ASSEMBLY, SERVICING AND STAGING EVENTS TO BE SUPPORTED BY OMV. MAY REQUIRE TWO OMV ROUND TRIPS FOR SOME EVENTS. CAPABILITY SHOULD BE INCREASED AS RAPIDLY AS POSSIBLE

POLAR PLATFORMS – NUMBER

	1992	1993	1994	1995	1996	1997	1998	1999	2000
CANADA				1					
ESA	1			1					
JAPAN						1		1	
NASA		2	1*			1			
NOAA	2								
OTHER U.S.								2	
	3	2	1	2	0	2	0	3	0

* Duration 2 years

OSS-271

CONFIGURATION PHILOSOPHY

S-85-00261A

- ACCOMMODATION OF USER REQUIREMENTS IS PRIME CONSIDERATION
  - AS CURRENTLY UNDERSTOOD
  - WITH VERSATILITY TO HANDLE NEW REQUIREMENTS
- OBJECTIVE IS TO CREATE A FACILITY, NOT A VEHICLE

Space Station Reference Configuration

NASA

BACKGROUND

S-85-00262A

- "SKUNK WORKS" EXERCISE STUDIED FIVE CONCEPTS IN SUMMER OF 1984
  - CONTINUITY WITH SPACE STATION TASK FORCE
  - FIVE CONCEPTS NARROWED TO THREE EARLY IN STUDY
    - CDG PLANAR (VARIABLE ORIENTATION)
    - DELTA TRUSS (SOLAR INERTIAL)
    - POWER TOWER (EARTH-ORIENTED)
- FAMILY OF CONFIGURATIONS SELECTED FOR PHASE B STUDY
  - TRUSS STRUCTURE
  - ARTICULATING SOLAR ARRAYS
  - MANNED MODULES
  - POWER TOWER IS MEMBER OF THIS FAMILY AND HAS MANY ATTRACTIVE FEATURES
- POWER TOWER ADOPTED AS REFERENCE CONFIGURATION FOR RFP
  - FOCAL POINT FOR DEFINITION AND ASSESSMENT OF REQUIREMENTS
  - BASIS FOR COST ESTIMATES
  - STARTING POINT FOR PHASE B STUDIES

NATURAL ATTRIBUTES OF REFERENCE CONFIGURATION FAMILY

S-85-00263

- EARTH-FIXED ORIENTATION
  - CONTINUOUS EARTH AND CELESTIAL VIEWING
  - SIMPLIFIED PROXIMITY OPERATIONS
  - SIMPLIFIED MOUNTING OF COMMUNICATIONS AND TRACKING ANTENNAS
  - ACCOMMODATES TETHERED EXPERIMENTS
  - GRAVITY GRADIENT STABILITY
  - TOLERATES MASS SHIFTS ALONG KEEL, ENHANCING GROWTH FLEXIBILITY
- LARGE OVERALL SIZE
  - REDUCED CONTAMINATION OF SENSITIVE INSTRUMENTS
  - AMPLE ROOM FOR SERVICING, CONSTRUCTION

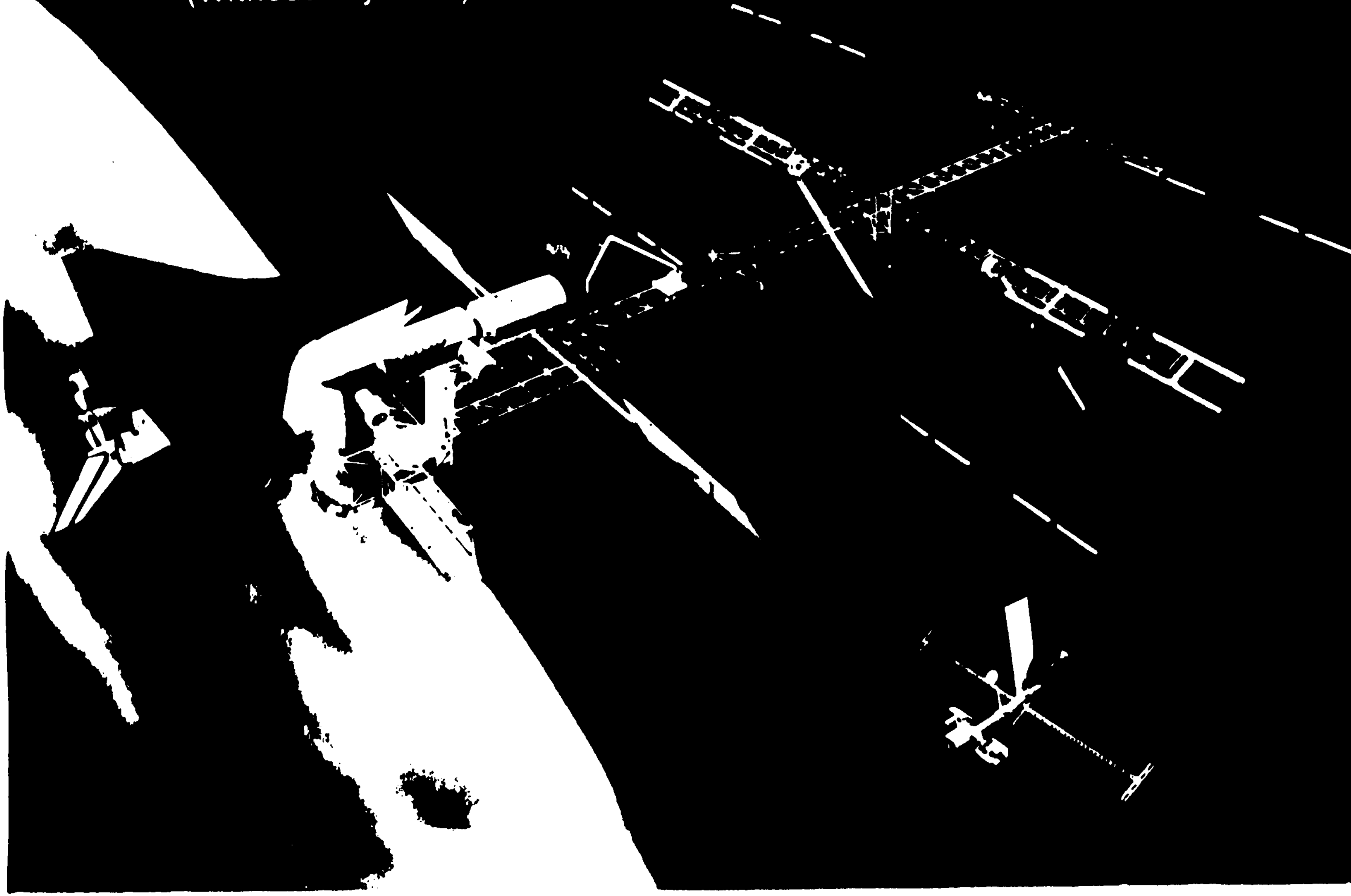
NASA National Aeronautics and Space Administration

Lyndon B. Johnson Space Center
Houston, Texas 77058

Space Station Reference Configuration

S-85-00299

IOC PHOTOVOLTAIC SPACE STATION
(Without Payloads)



BASIC SYSTEM REQUIREMENTS

S-85-00265A

- ELECTRICAL POWER - 75 kW TOTAL, 50 kW TO USERS
- CREW SIZE - 6 TOTAL, 4 FOR USER SUPPORT
- PRESSURIZED LABORATORY VOLUME - 45-90 CU. METERS
- ORBITAL MANEUVERING VEHICLE (OMV) ACCOMMODATIONS

S-85-00266

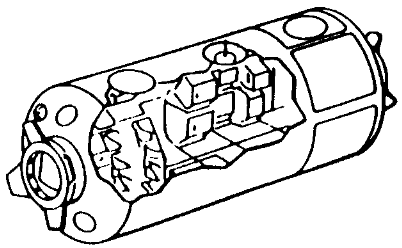
USER ACCOMMODATION REQUIREMENTS (PARTIAL LIST)

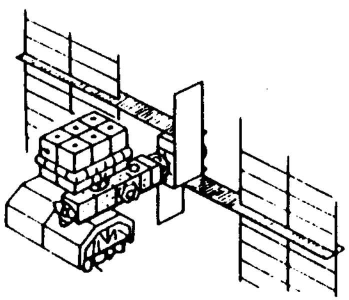
- USER REQUIREMENTS EXPECTED TO CHANGE; REQUIREMENTS FOR IOC INTENDED TO ASSURE COMPATIBILITY OF STATION WITH ANY LIKELY SET OF USER PAYLOADS
- SIMULTANEOUS SOLAR, STELLAR, EARTH AND ANTI-EARTH OBSERVATION
- CONTINUOUS LIMB-TO-LIMB VIEWING
- "FORWARD" - FACING INSTRUMENT - CARRYING PORTION OF STATION REMAINS FORWARD CONTINUOUSLY DURING PERIOD OF OBSERVATION
- LOW GRAVITY ($<=0.00001$ G) FOR EXTENDED PERIODS
- PRESSURIZED PERMANENT LABORATORY SPACE
- PRESSURIZED AND UNPRESSURIZED ATTACHED PAYLOADS
- RETRIEVAL AND DELIVERY OF SATELLITES TO REMOTE ORBITS
- ON-BOARD SERVICING AND MAINTENANCE OF SATELLITES
- REMOTE, UNMANNED SERVICING OF SATELLITES
- CONSTRUCTION AND DEPLOYMENT OF LARGE SPACE SYSTEMS
- EXTRAVEHICULAR ACTIVITY
- TETHERED SUBSATELLITES

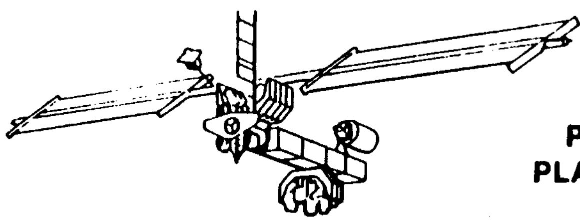
NASA
S-85-00950

Space Station
European Space Agency Reference Configuration

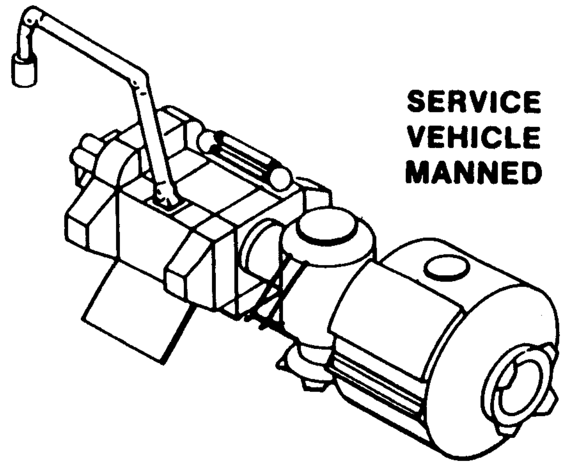
INITIAL

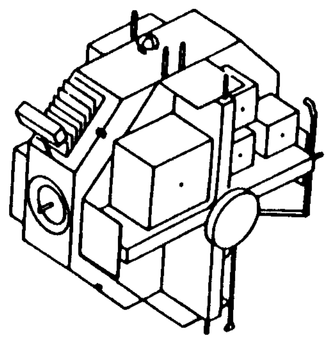

PRESSURIZED MODULE


CO-ORBITING PLATFORM


POLAR PLATFORM

GROWTH

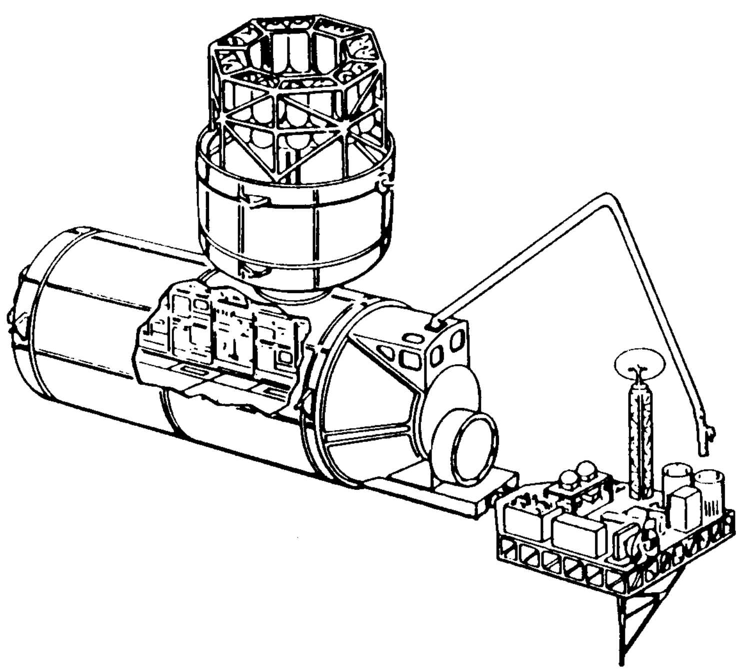

SERVICE VEHICLE MANNED


UNMANNED

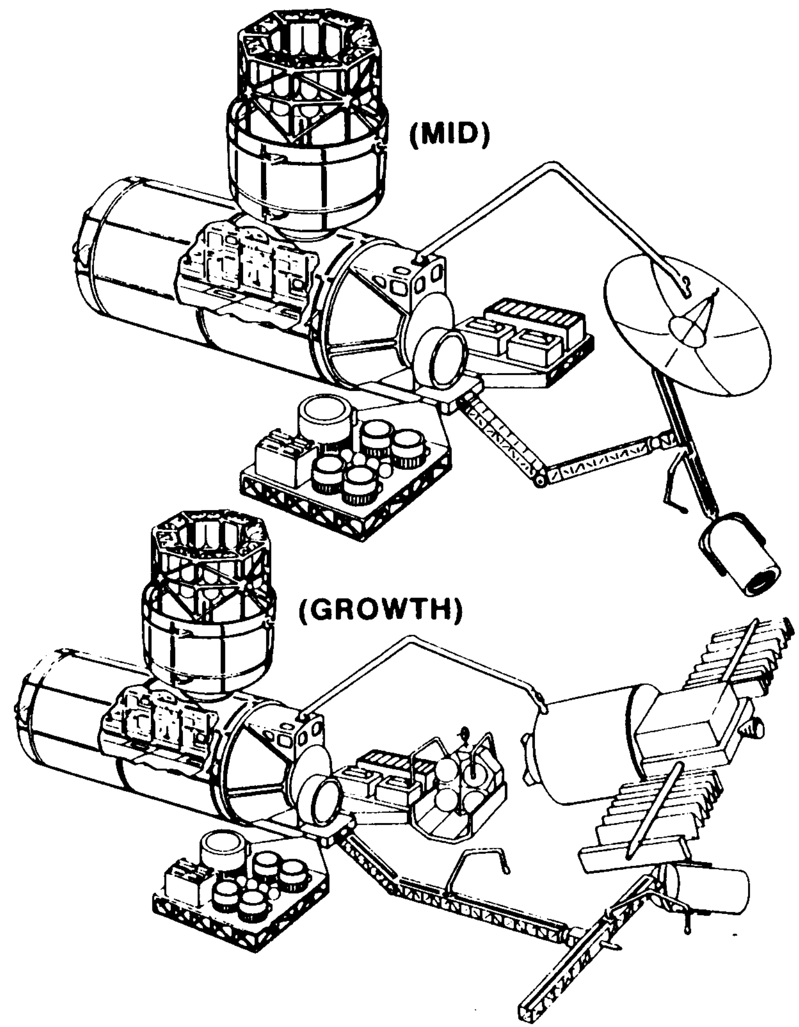
S-85-00951

Space Station
Japanese Reference Configuration

INITIAL



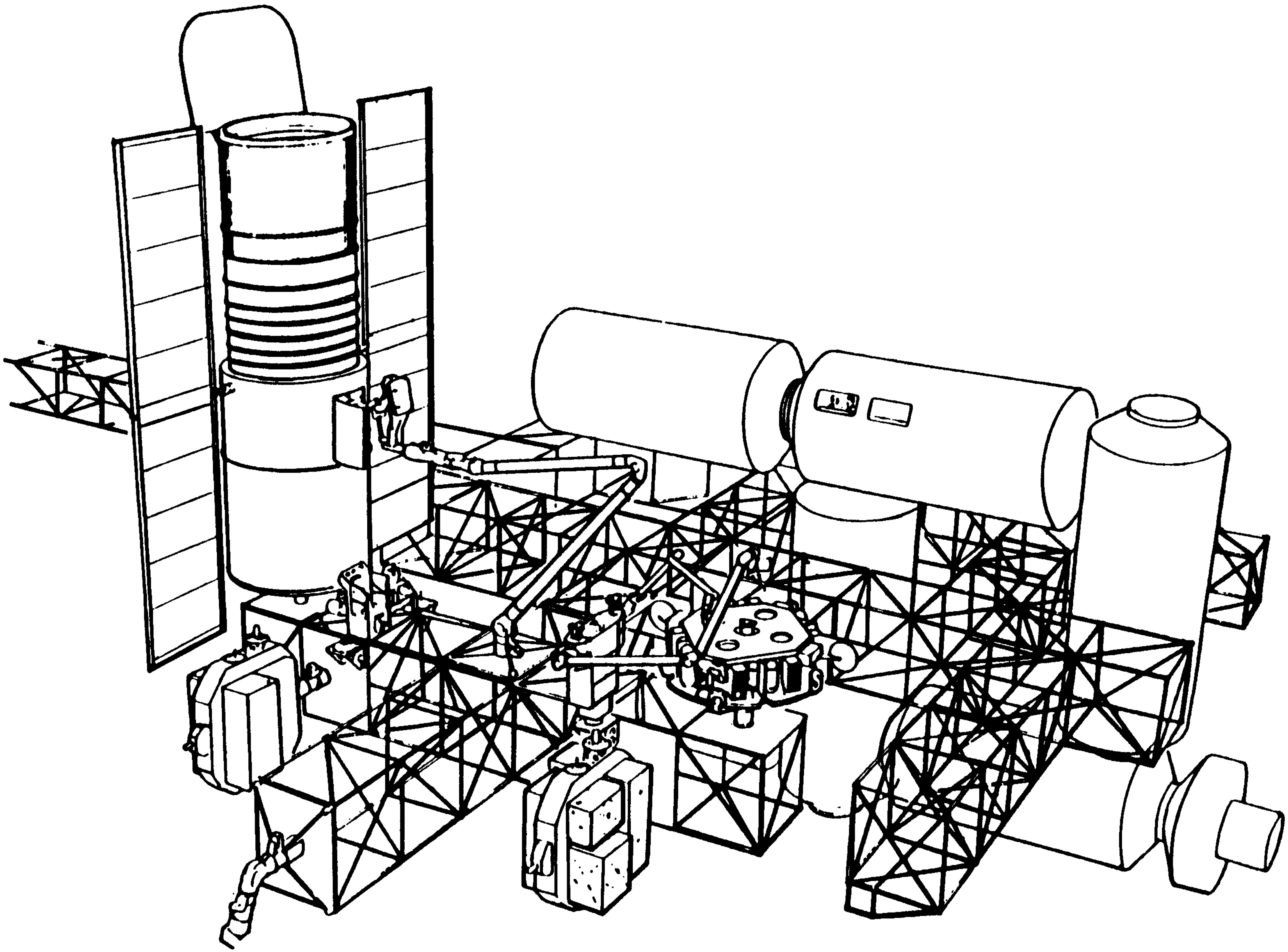
GROWTH



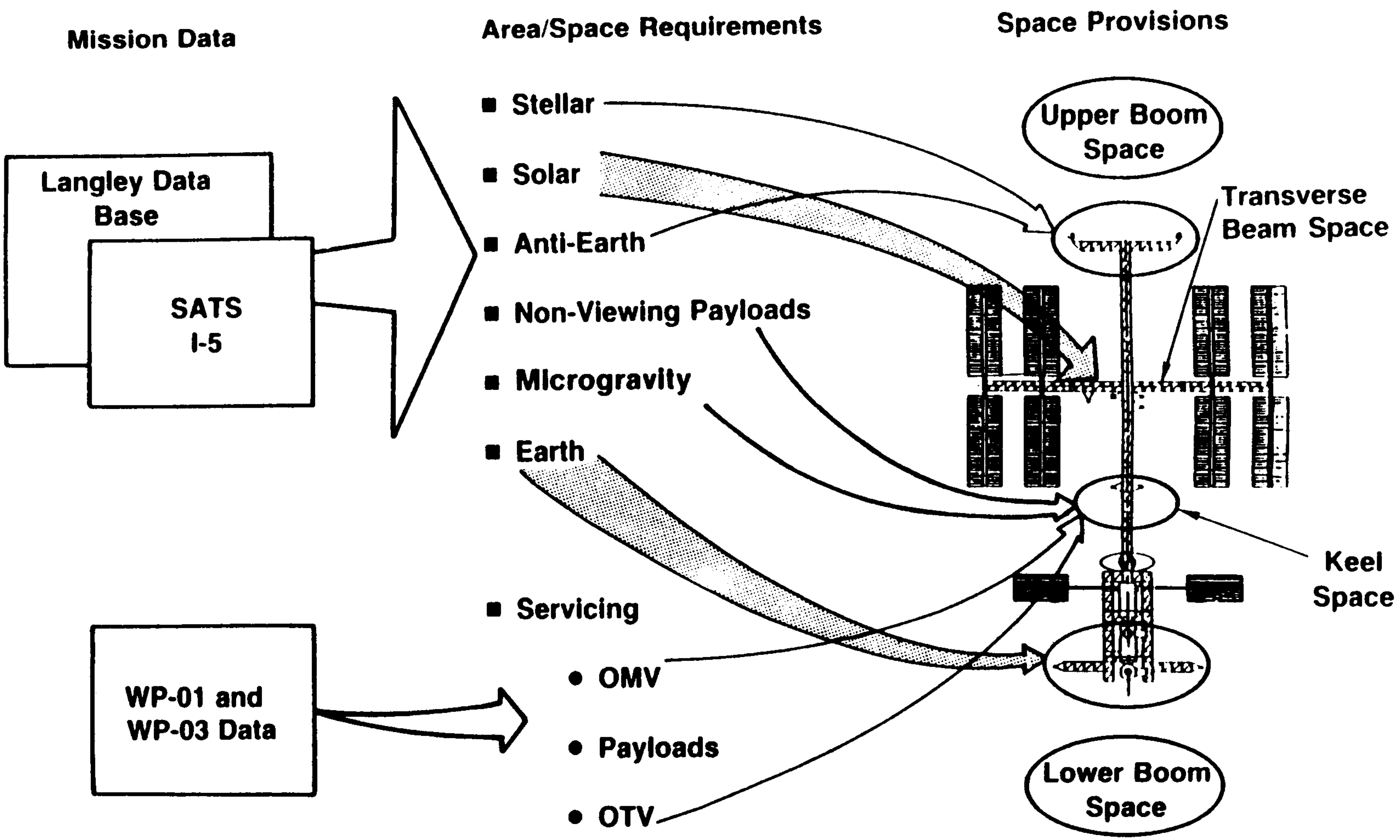
Space Station Reference Configuration

CANADIAN SERVICING FACILITY

S-85-01892



CONFIGURATION REQUIREMENTS ANALYSIS M-3

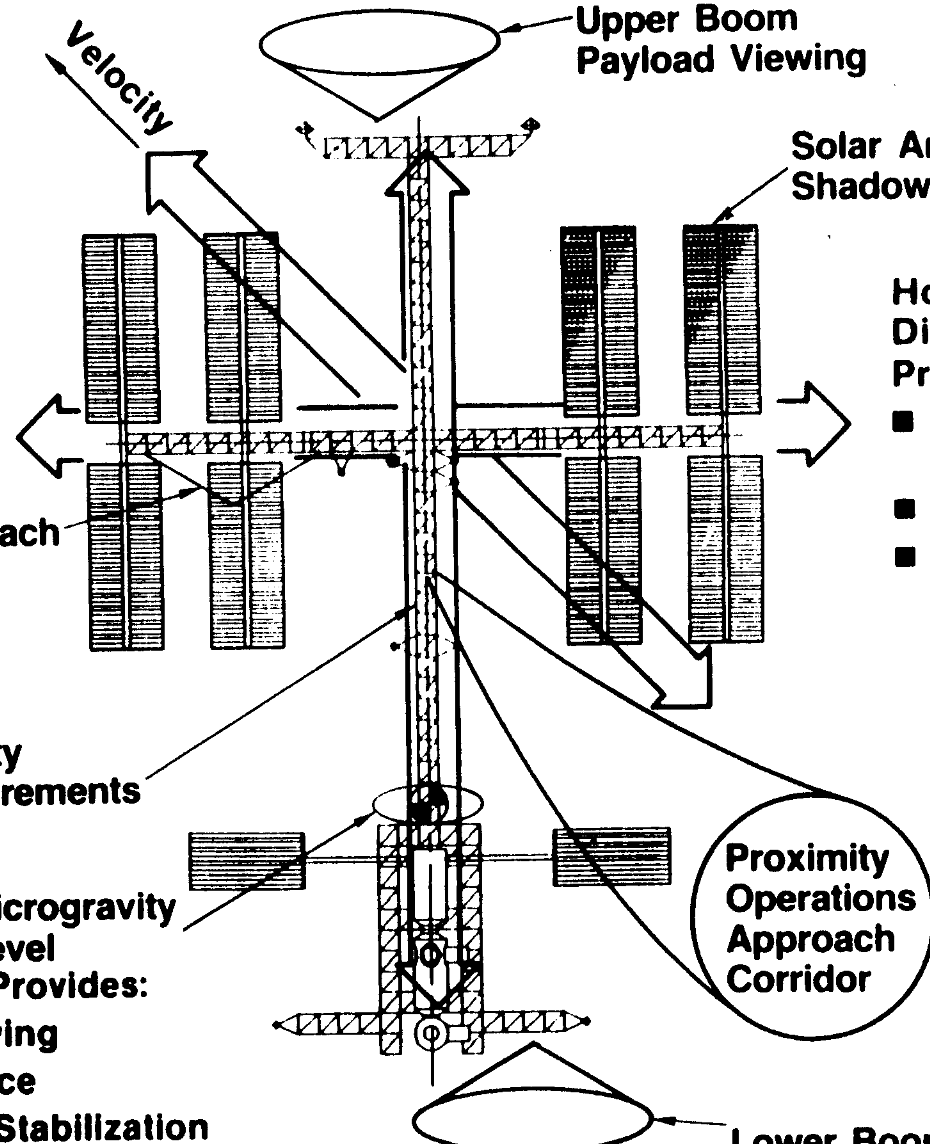


CONFIGURATION SPATIAL DESIGN ISSUES

VHH544

M-12

Flight Path Dimension Provides:
- Maximum Micro-gravity Space
- NSTS Docking Offset

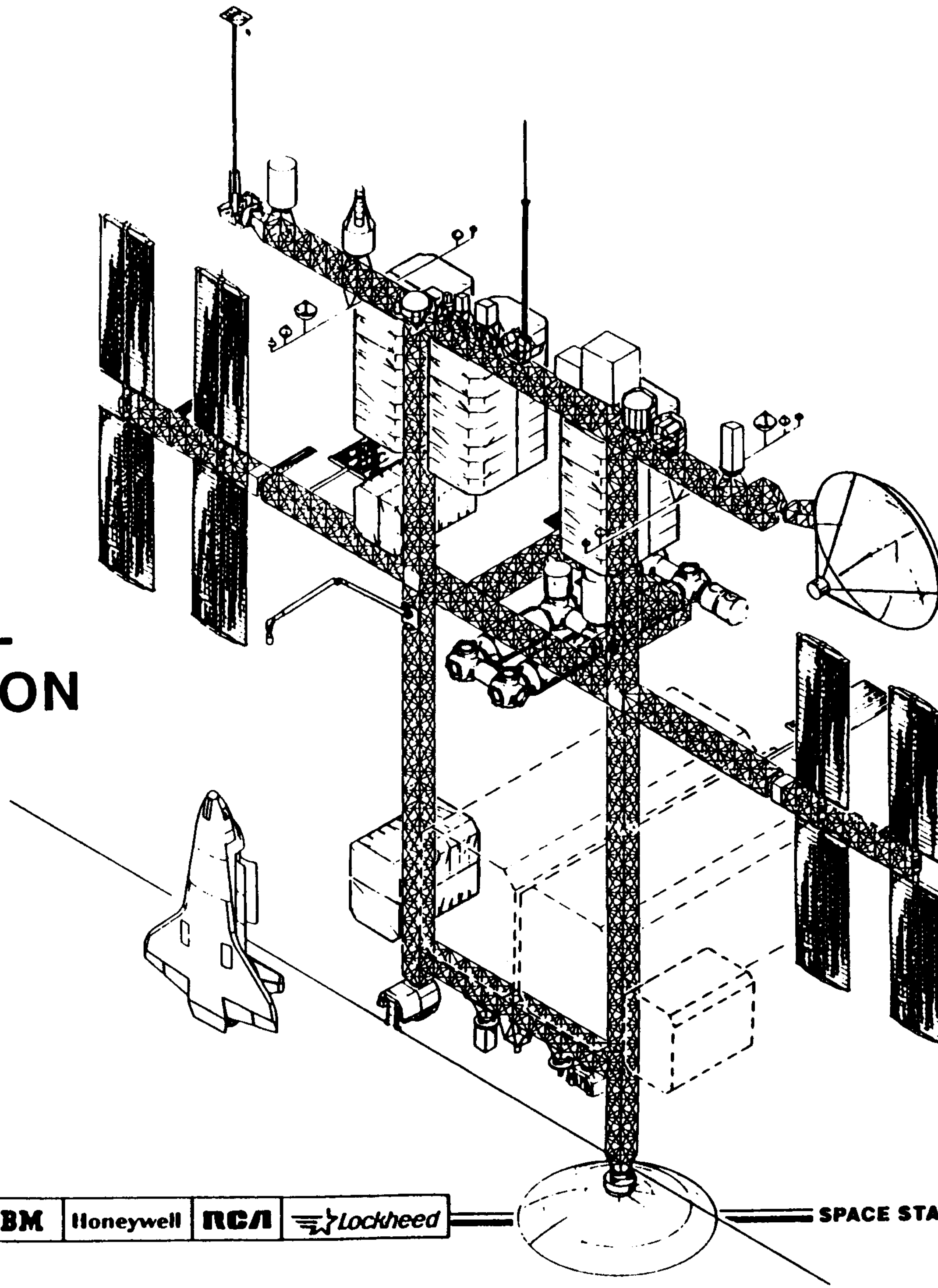


Horizontal Dimension Provides:
- Solar Collector Viewing
- Power Growth
- Prox Ops Corridor Clearance

Vertical Dimension Provides:
- Zenith/Nadir Viewing
- Keel Payload Space
- Gravity-Gradient Stabilization

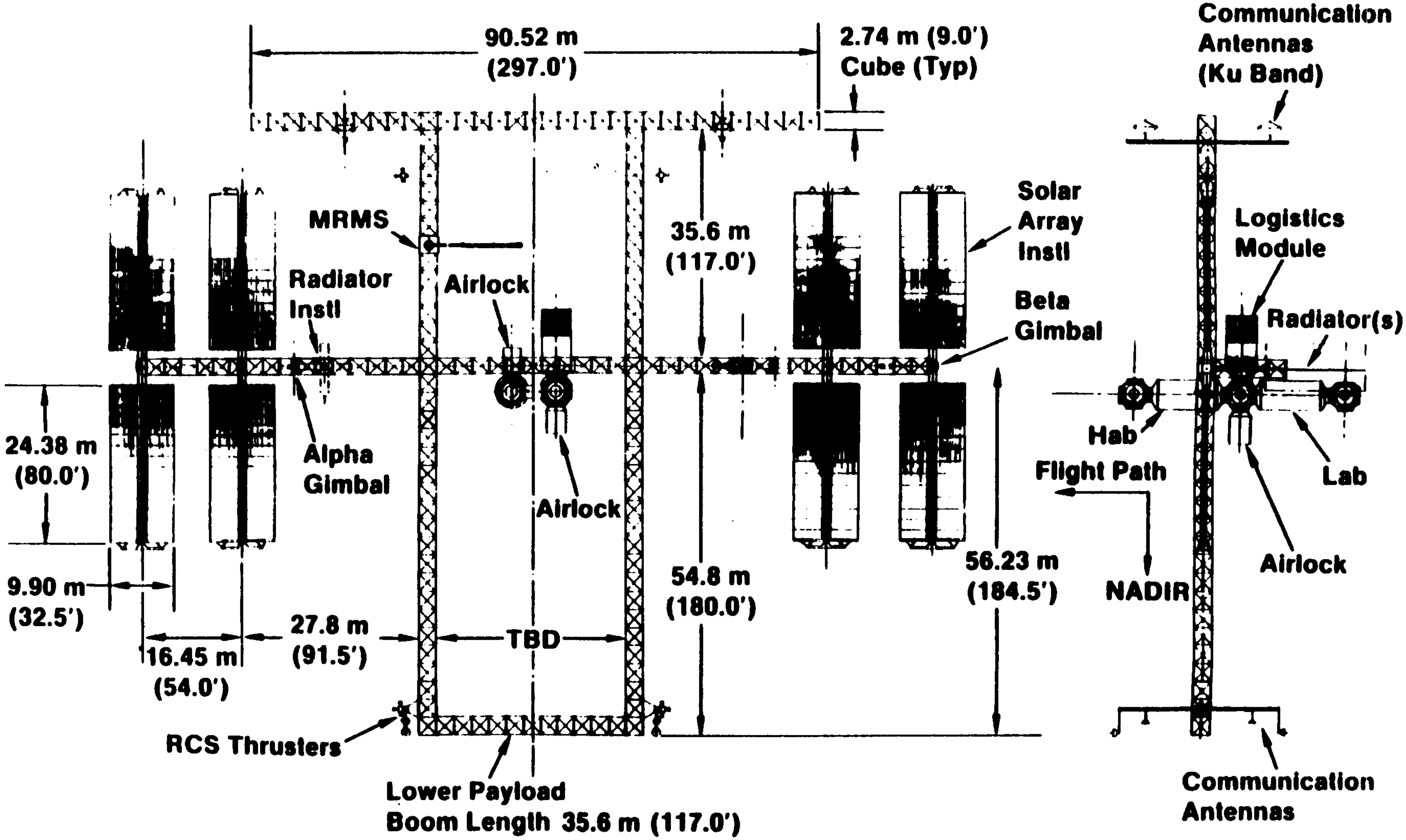
VHK093

DUAL KEEL SPACE STATION

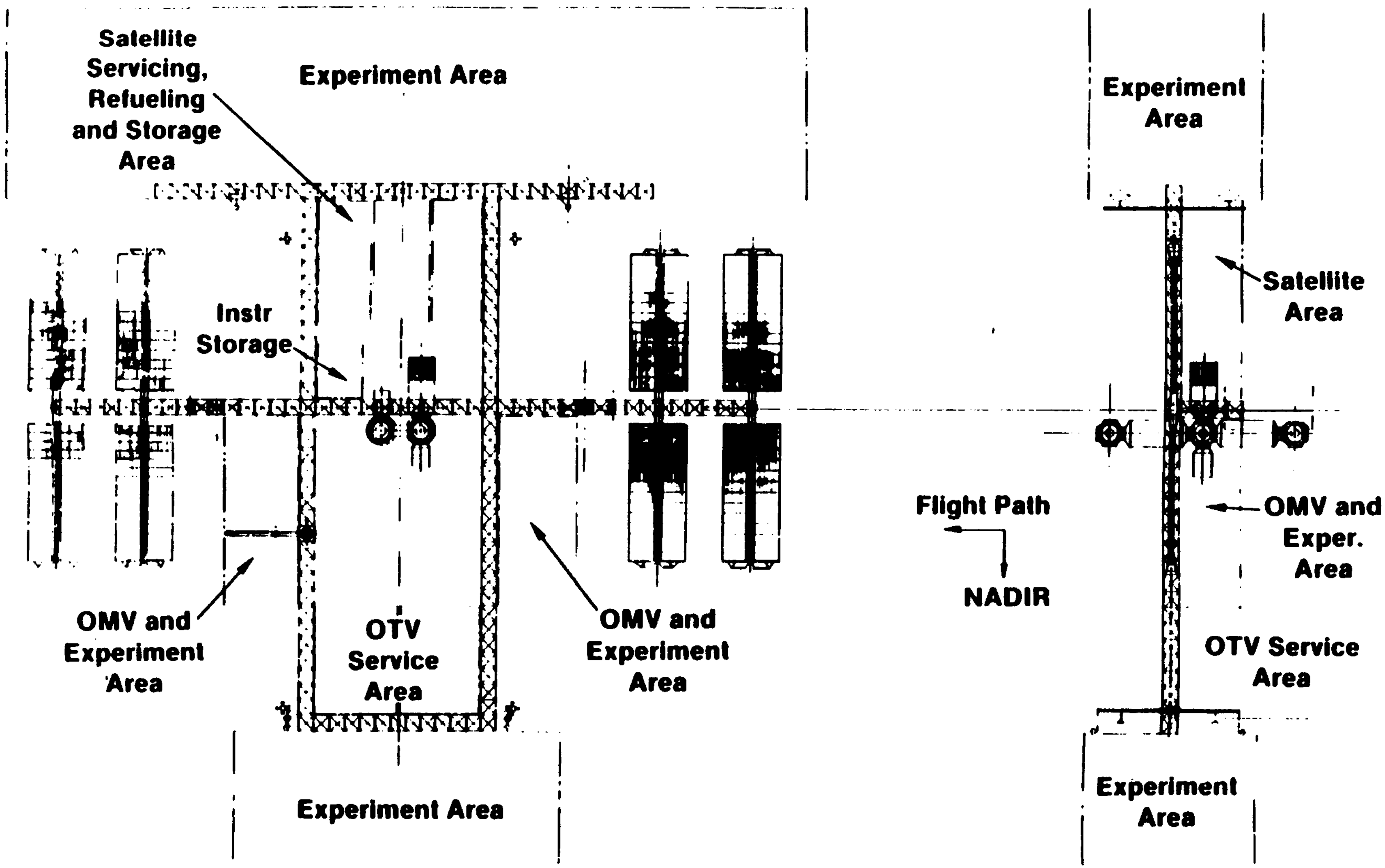


MCDONNELL DOUGLAS CORPORATION | IBM | Honeywell | RCA | Lockheed — SPACE STATION PROGRAM

MANNED CORE SPACE STATION



MANNED CORE SPACE STATION PAYLOAD ACCOMMODATIONS



UPPER BOOM CANDIDATES

MISSION ID		SATS	VIEWING		SIZE				OPERATION											
					L	W	H	MASS												
CODE	NAME		DIR	FOV	M	M	M	KG	HR/DAY	92	93	94	95	96	97	98	99	00	01
SAAX 0001	CRN	ALL	AE	140°	3.3	4.8	3.8	3,082	24	180	365	180							
SAAX 0021	SUPER MAGNET	ALL	AE	140°	3.3	4.8	0	5,650	24			90	365 DAYS/YEAR						365
TDMX 2441	OPTICS DATA SYSTEM	ALL	AE	$\boxed{5}$	2	1	0.5	200	24					365					
*S003	HE COSMIC RAY	ALL	AE	180°	2	2	1.5	2,000	1	60		60		100			100		
S004	COSMIC ↑ RAY BURSTS	1,3,4,5	AE	180°	1.5	1	0.5	500	24			365							
TDMX 2011	S/C MATL/COATING	ALL	VEL/WAKE	90°	15	1	0.2	930	24					365					
SAAX 0011	ASO	ALL	S	3°	32	5	5	12,500	17		180				365				
SAAX 0207	SOLAR TERR OBS	ALL	(SE GEOMAG)	$\boxed{180°}$	$\boxed{3}$	$\boxed{4}$	$\boxed{4}$	$\boxed{1,300}$	8			365							
TDMX 2153	SD PWR	ALL	S	90°	29	12.5	12.5	1,325	24		365								
TDMX 4004	SOLAR CELLS	1,2,4,5	$\boxed{S}$	0	10	2	0.3	100	24	90									
T007	2D SOLAR ARRAY	1,3,4,5	S	0	6	6	0.6	130	0.5			20							
T008	SOLAR THERMAL GEN	ALL	S	0	4	4	0	1,500	12							365			
S005	LINE GAMMA DETECTION	1,2,4,5	STELLAR	60°	1.0	1.0	1.0	500	24				365						
TDMX 2541	ELECTRODYNAMIC PWR GEN.	ALL	TETHER UP	–	$\boxed{3}$	$\boxed{1}$	$\boxed{1}$	8,000	24			30			10				
TDMX 2542	TETHERED CONSTELL.	ALL	TETHER UP	–	15	1	0	30	8			300		300		300		300	
S002	IR TELESCOPE IN SPACE	1,2,4,5	INERTIAL	180°	5.5	2.5	0	1,500	12			365		365					

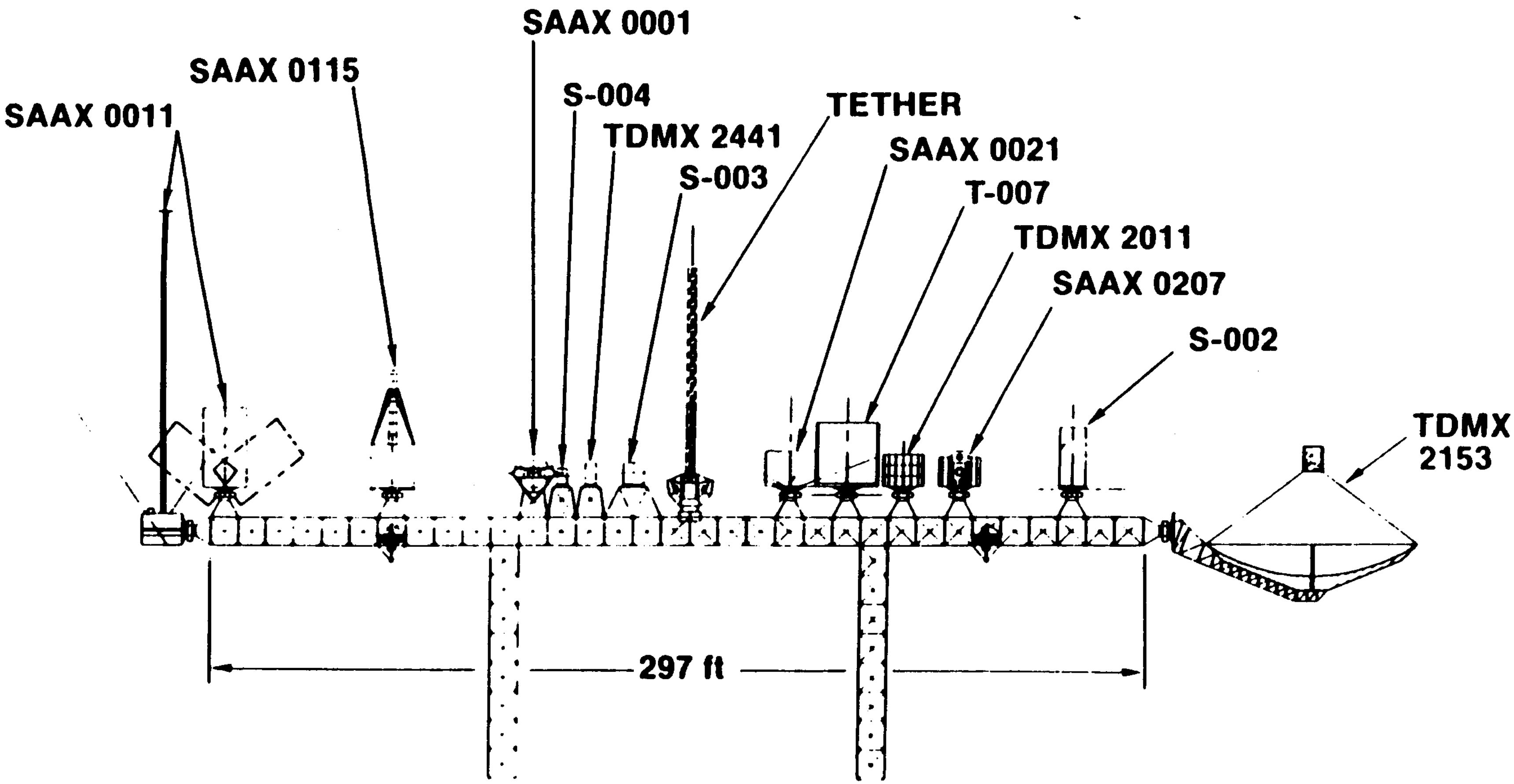
☐ MDAC DATA ESTIMATES

*S-003 DELAYED 5 YEARS IN SATS 2

VHK091

M-6

UPPER BOOM RECOMMENDATION
(1993/1994)

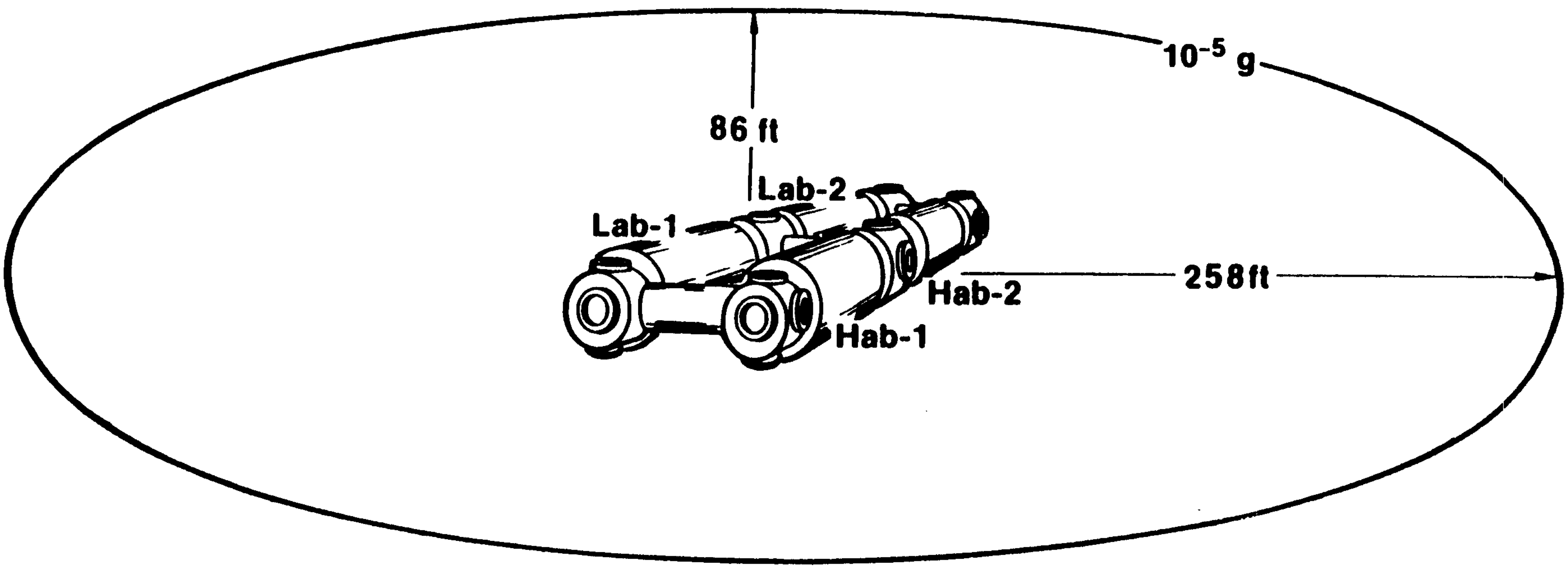


VHH545

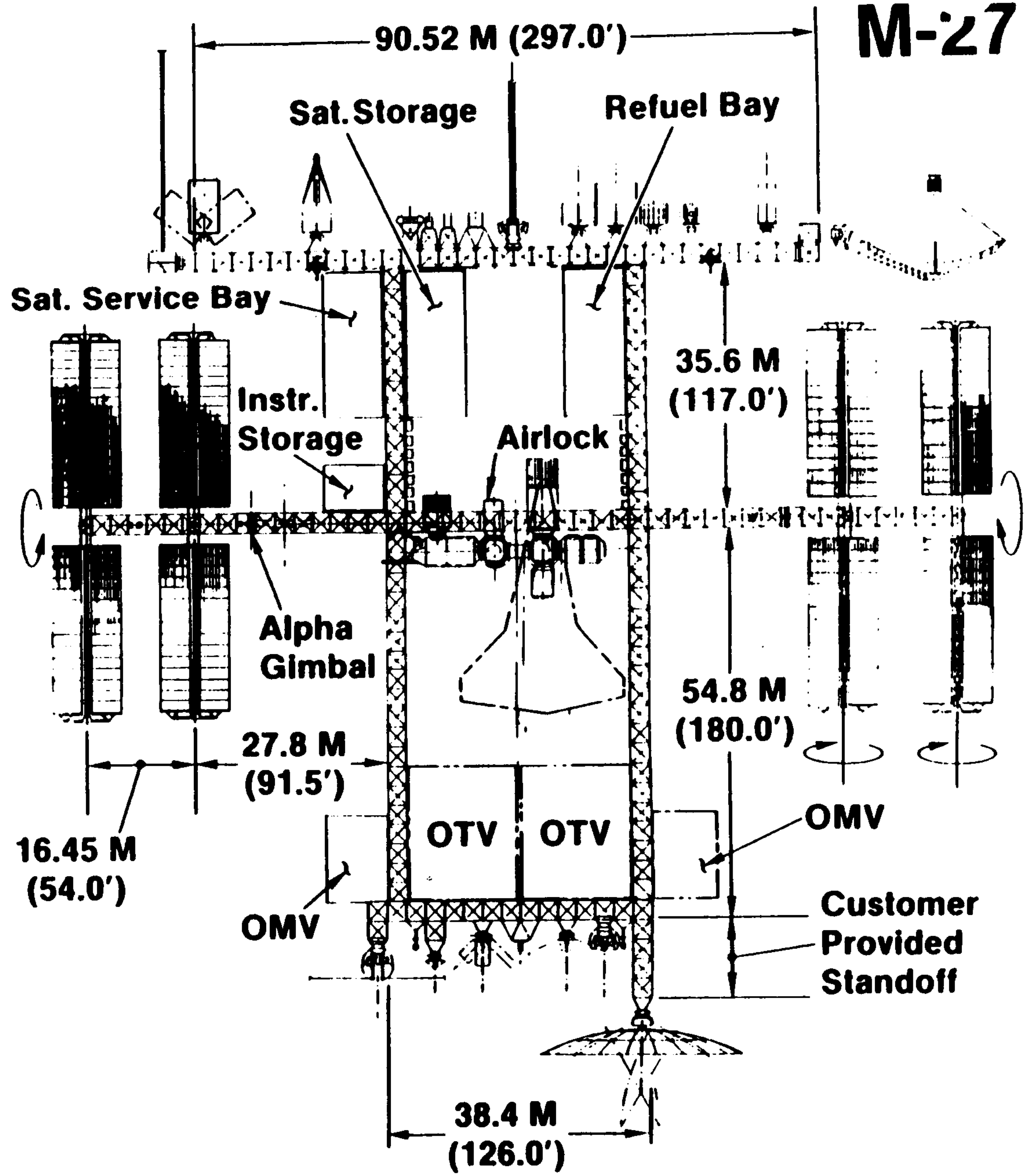
M-17

MODULES ARE AT THE CENTER-OF-GRAVITY

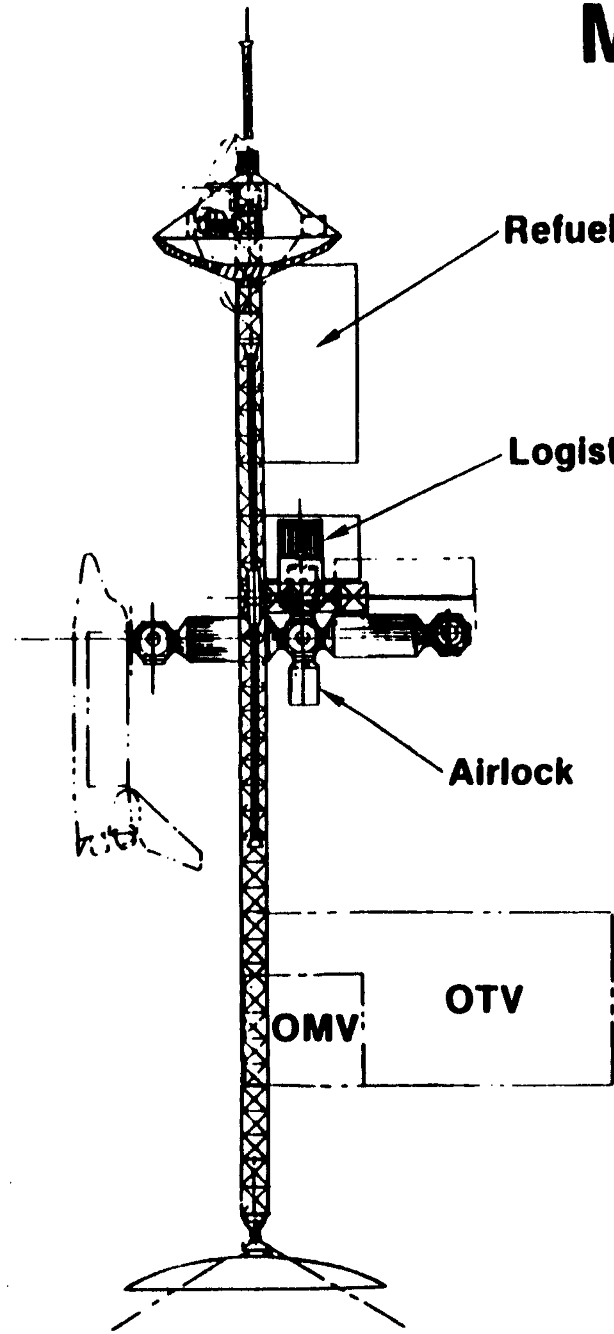
GRAVITY GRADIENT EFFECTS



DUAL KEEL — 1994



DUAL KEEL — 1994
(MODULES FORWARD)

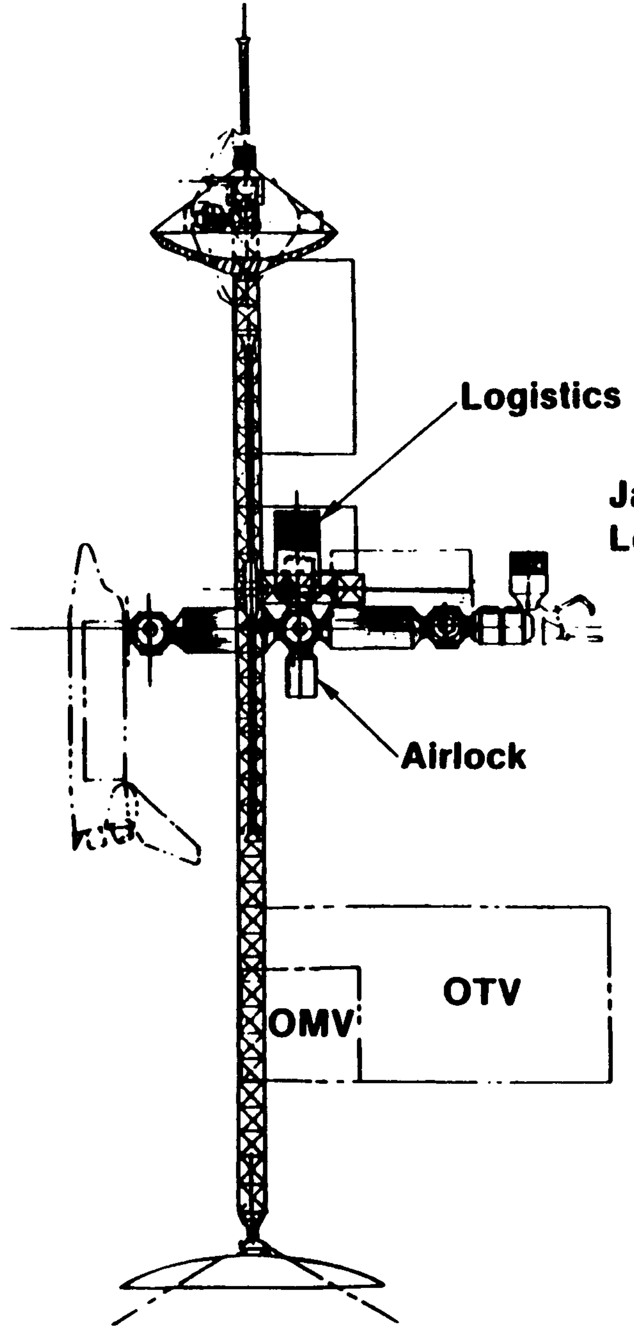


MCDONNELL DOUGLAS CORPORATION | IBM | Honeywell | RCA | Lockheed — SPACE STATION PROGRAM

VHK077

M-32

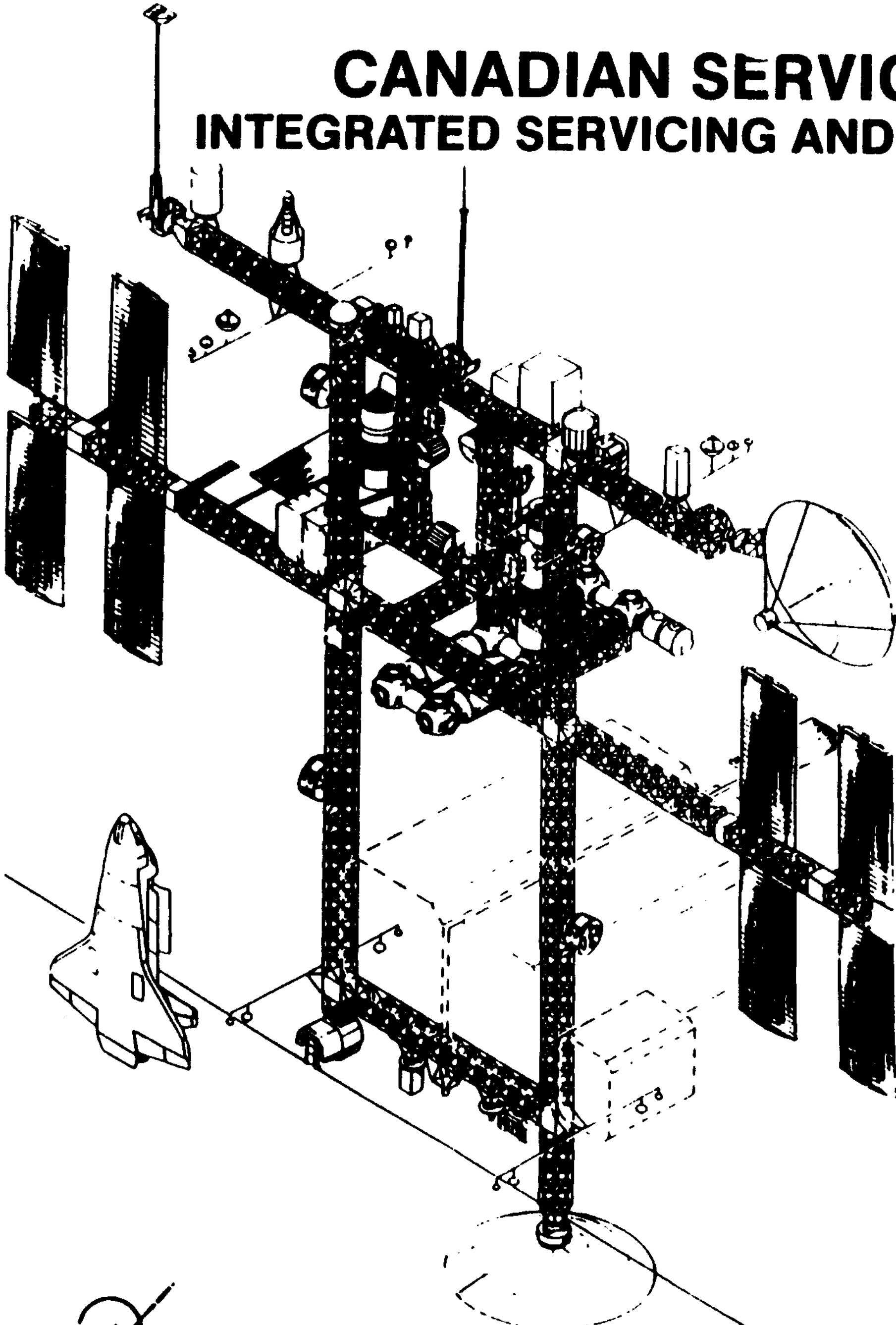
INTERNATIONAL MODULE ACCOMMODATION



CANADIAN SERVICE FACILITY

VHK6..

INTEGRATED SERVICING AND TEST FACILITY (ISTF) M-33

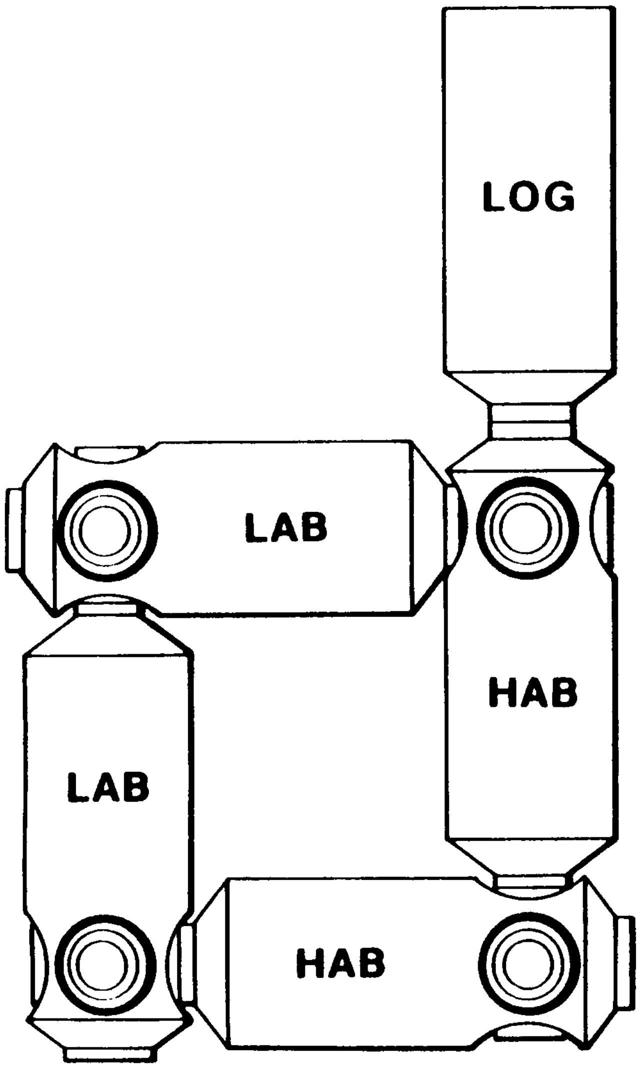


- Satellite Servicing
- Tool Storage
- OMV Servicing
- Robotic Servicer System
- MRMS Home Base

Space Station Reference Configuration

REFERENCE MODULE PATTERN

S-85-00292



KEY FEATURES

- RACETRACK
- HIGH MODULE COMMONALITY
- MINIMUM TOTAL NUMBER OF ELEMENTS
- MINIMUM NUMBER OF INTERFACES
- TRAFFIC THROUGH LABS MINIMIZED
- USABLE VOLUME IN MODULES IMPACTED BY PORTS

NASA

S-85-01719

Alternate Indirect Connect Patterns

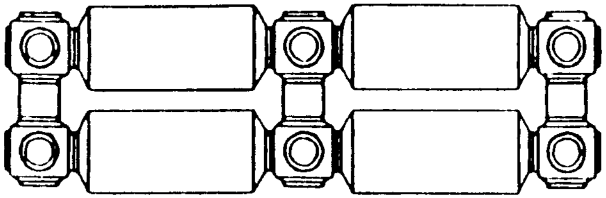
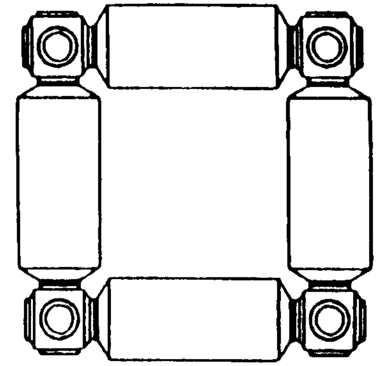
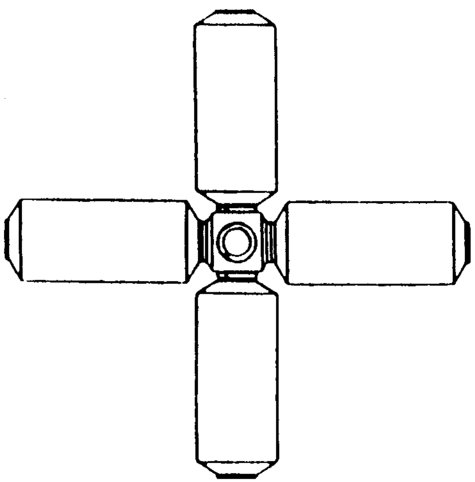


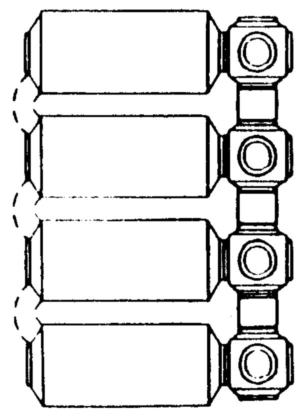
FIGURE EIGHT



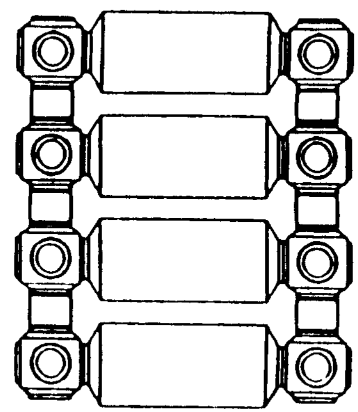
RACETRACK



PINWHEEL



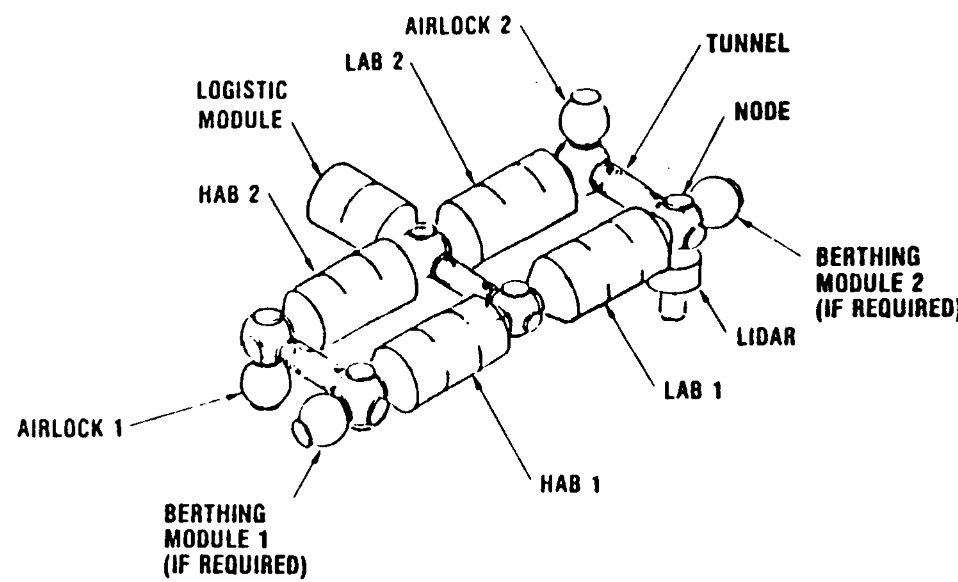
COMB



LADDER

Figure 8 Pattern Provides Versatility and Cost Savings Capabilities

- PROVIDES TWO WAYS OUT WITH TWO MODULES
- GROWTH FLEXIBILITY
- CLEAR INTERIOR
- PORTS AVAILABLE FOR PAYLOADS, & AIRLOCKS
- NODES COMMON ELEMENTS — MODULE CONNECT & AIRLOCK
- COMMON MODULES WITH COMMON NODES PERMIT COST SAVINGS WHEN USED WITH AIRLOCKS, BERTHING MODULES, AND OTHER OPERATIONS FACILITIES



GENERAL ARRANGEMENT

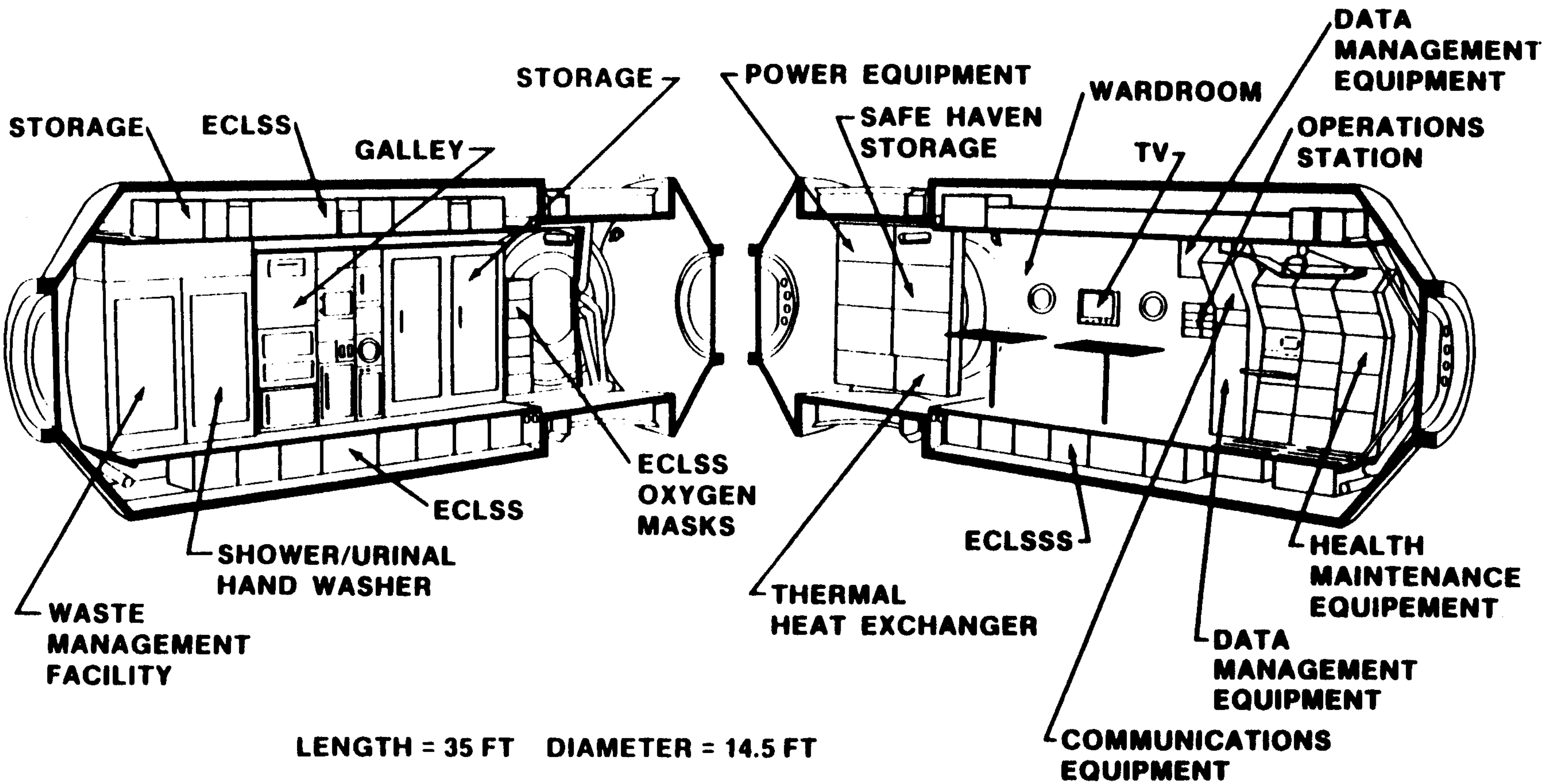
Rockwell International
Space Station Systems Division

95SSS163862B

Space Station Reference Configuration

HAB 1 MODULE

S-85-00251A

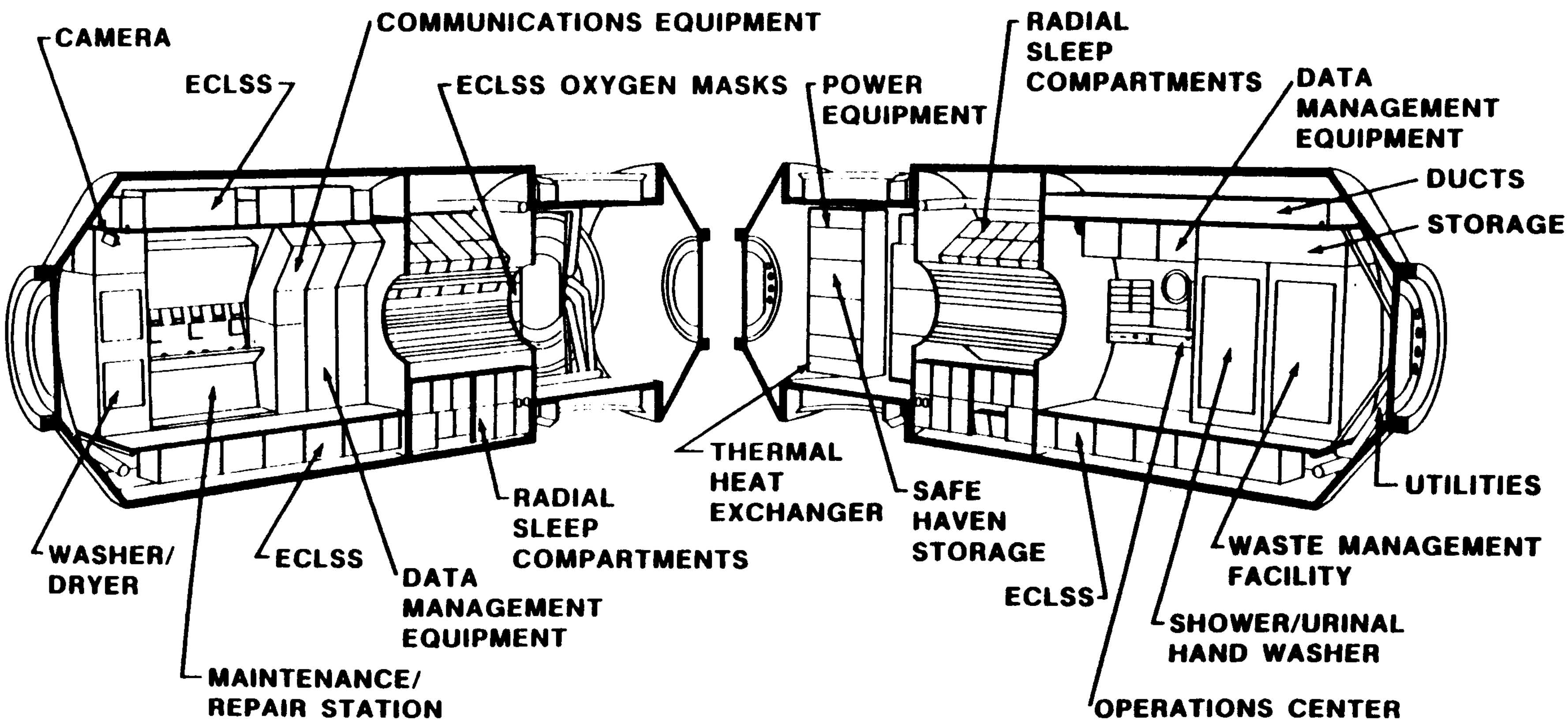


LENGTH = 35 FT   DIAMETER = 14.5 FT

Space Station Reference Configuration

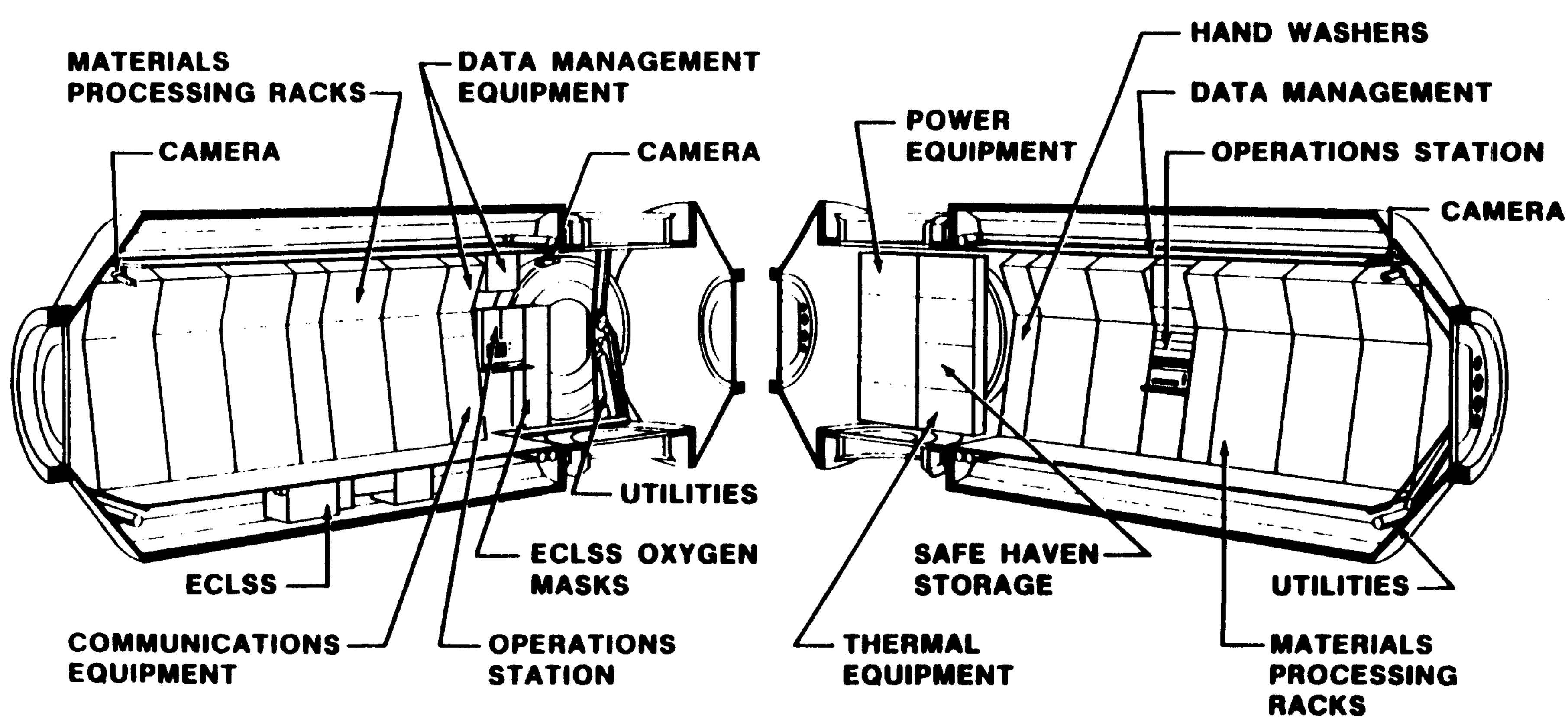
HAB 2 MODULE

S-85-00250



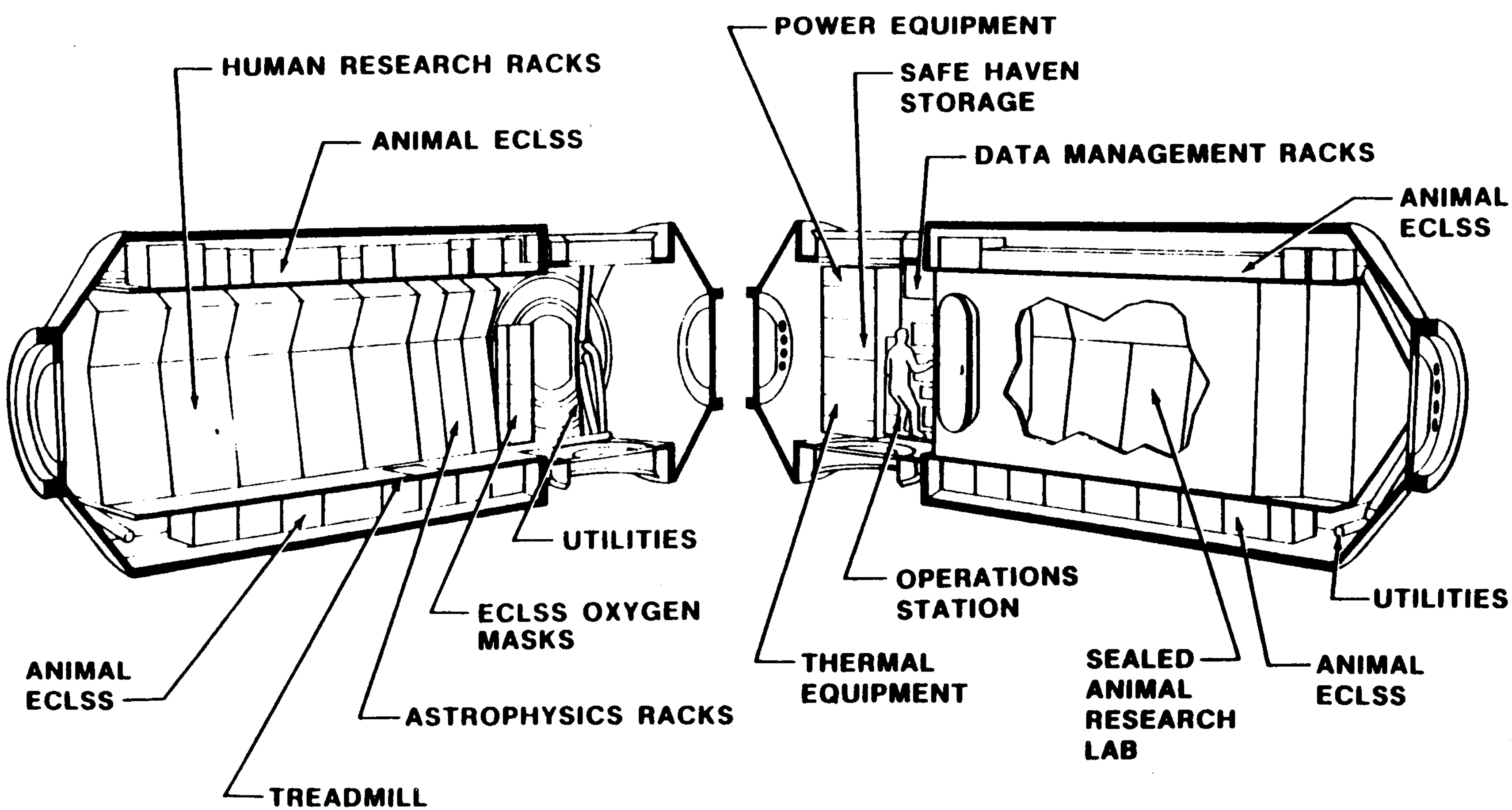
MATERIALS PROCESSING LAB

S-85-00252



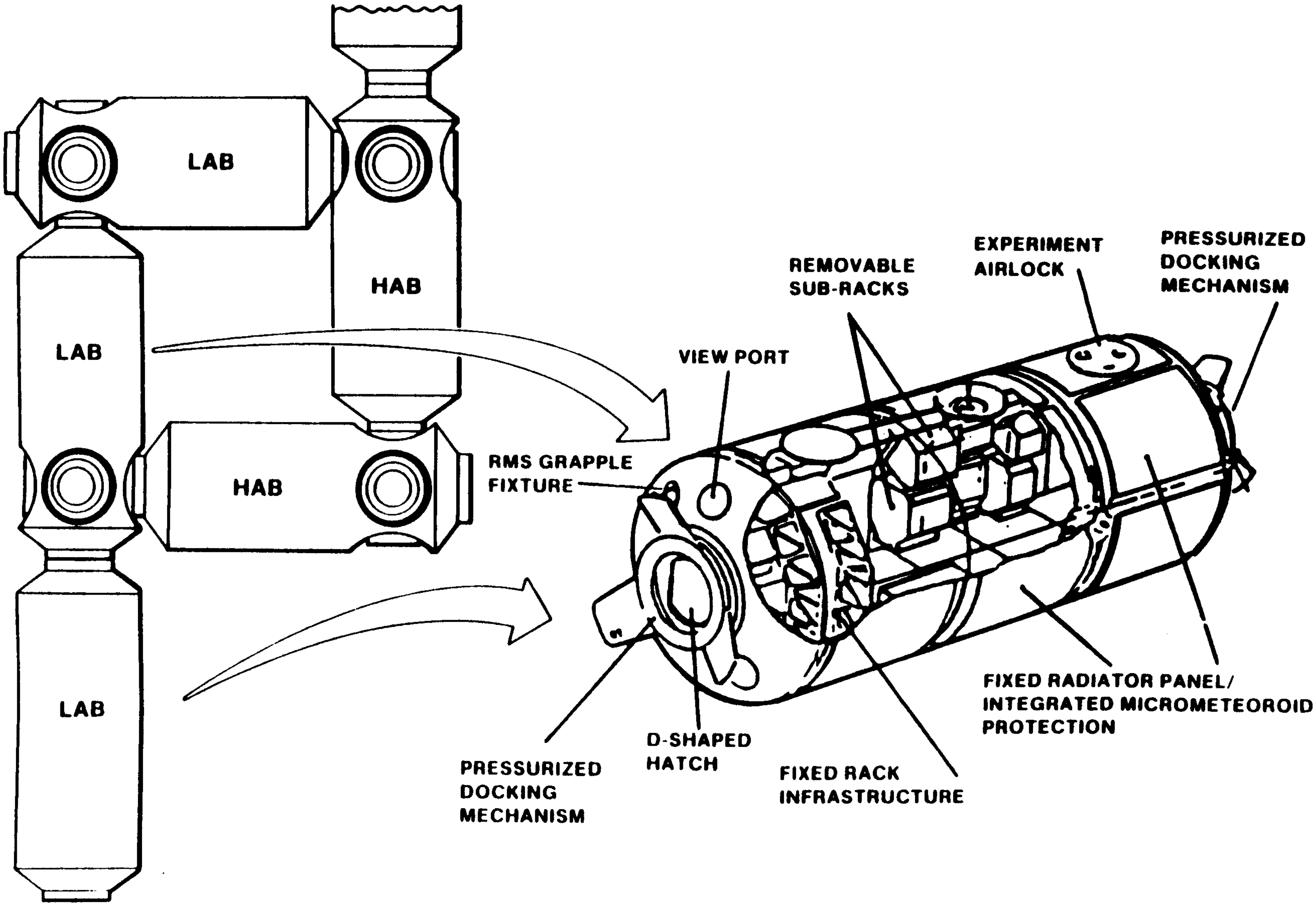
LIFE SCIENCE LAB

S-85-00271

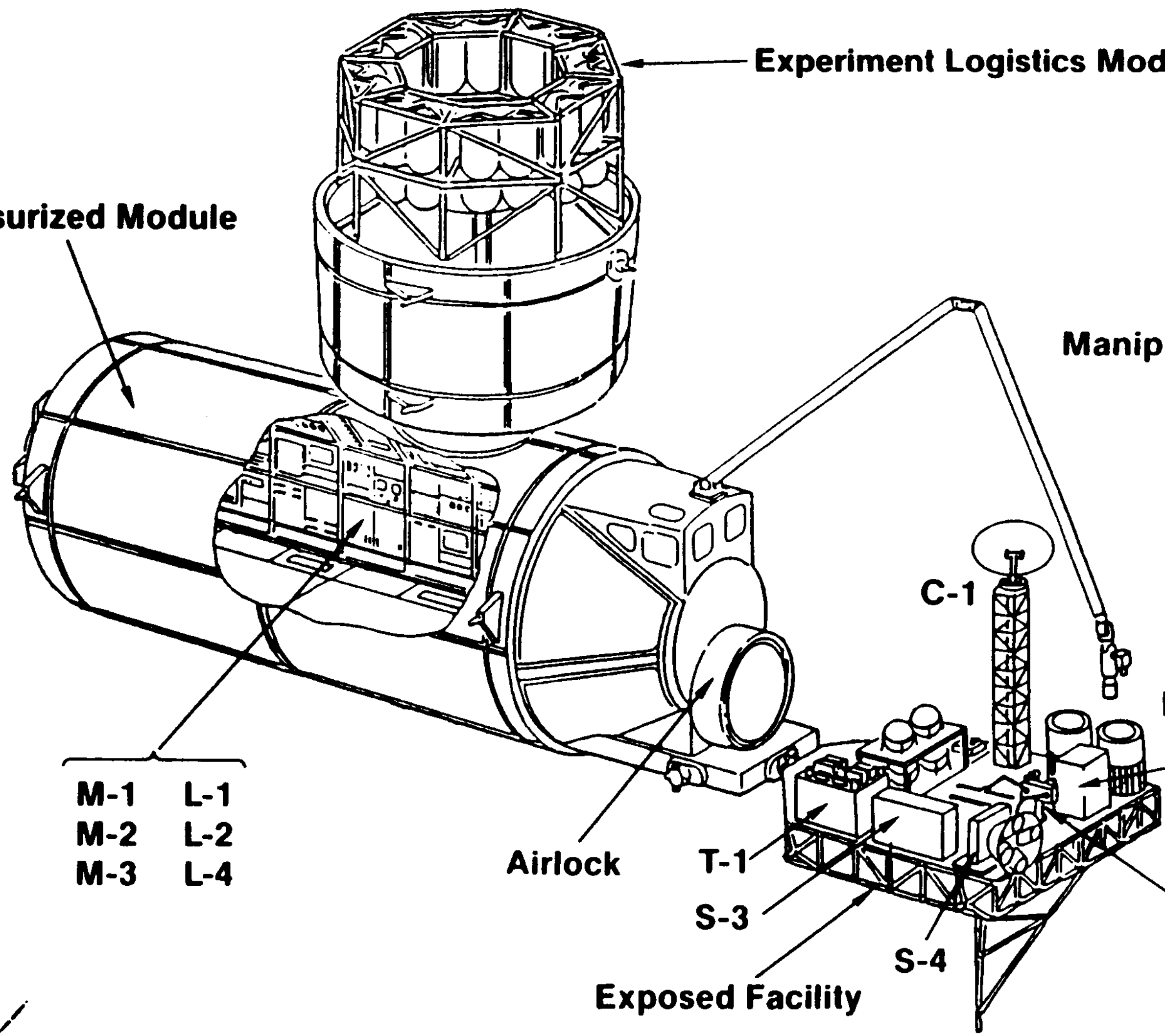


ESA LAB MODULE

S-85-01879



EXAMPLE OF PAYLOAD ACCOMMODATION (INITIAL PHASE)



CONFIGURATION FEATURES FOR USER ACCOMMODATIONS

S-85-00268

- CONSTANT ORIENTATION RELATIVE TO EARTH
  - CONTINUOUS EARTH VIEWING FROM LOWER END OF STATION
  - VIEWING OF VISIBLE SKY (SUN AND STARS) FROM UPPER END OF STATION
  - SAME FACE FORWARD AT ALL TIMES
  - FIXED TETHER ATTACH POINTS
- LARGE OVERALL DIMENSIONS
  - AMPLE VOLUME FOR SERVICING, CONSTRUCTION
  - SENSITIVE PAYLOADS SEPARATED FROM CONTAMINATION SOURCES
  - GRAVITY GRADIENT STABILITY
- PRESSURIZED VOLUME
  - TWO LABORATORY MODULES
  - HABITATION AND STATION OPERATIONS SEPARATE FROM LABS
  - "RACETRACK" LAYOUT PERMITS ISOLATION OF LABS FROM TRAFFIC PATTERN AND FROM EACH OTHER WITHOUT COMPROMISING SAFETY
- FACILITIES
  - MULTIPLE PORTS FOR PRESSURIZED AND UNPRESSURIZED PAYLOADS
  - MOBILE MANIPULATOR
  - TWO EVA AIRLOCKS
  - ORBITAL MANEUVERING VEHICLE (OMV)
  - SATELLITE RETENTION FIXTURES

S-85-01887

Internal Pressure

- EXAMINING BOTH 10.2 AND 14.7 PSIA
- SIGNIFICANT CONTROVERSY SURROUNDING TOPIC
- 10.2 PREFERRED TO ALLOW MINIMUM EVA SUIT PRESSURE/OPTIMUM PREBREATHE
- 14.7 PREFERRED TO ALLOW "NORMALCY"
  - PAYLOAD EQUIPMENT
  - EXPERIMENT PROTOCOLS (EARTH BASED DATA BASE)
  - AVOID POWER/COOLING PENALTY
  - MATERIALS COMPATIBILITY (10.2 RUNS PP02 UP TO 30%)
- ADDED STUDY OF 12.0 AS POSSIBLE COMPROMISE
- DECISION SCHEDULED BEFORE RUR-2; EXPECT CLOSER TO 14.7 THAN 10.2 BASED ON EVIDENCE TO DATE

GROWTH CONFIGURATION

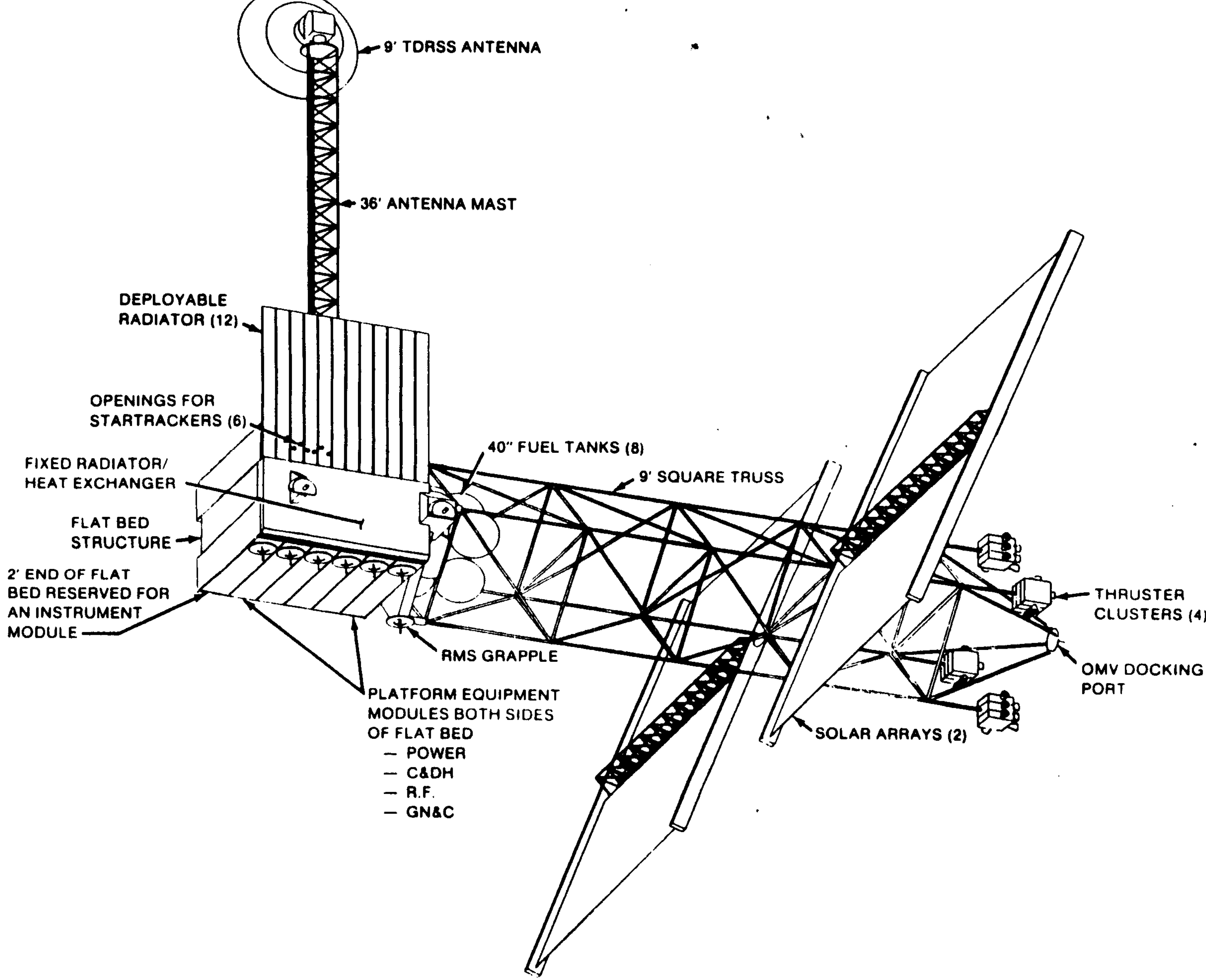
S-85-00264A

- STATION MUST GROW TO ACCOMMODATE INCREASING USER DEMANDS
  - SPECIFIC REQUIREMENTS NOT WELL DEFINED; ASSUME SOME INCREASED NEEDS IN ALL AREAS
  - INCREASED POWER (300 kW) AND THERMAL REJECTION
  - LARGER CREW (14)
  - MORE PRESSURIZED VOLUME (180 CU. METERS)
- EXPAND IOC CONFIGURATION WHERE POSSIBLE
  - ADDITIONAL QUADRANGLE OF MODULES UNDER EXISTING MODULES PLUS TWO LAB MODULES ATTACHED TO SIDE PORTS FOR TOTAL OF SIX LAB, FOUR HABITATION MODULES
  - CONVERT TO SOLAR DYNAMIC POWER SYSTEM; FEASIBILITY OF PHOTOVOLTAIC SYSTEM QUESTIONABLE AT 300 kW

GROWTH MODES

S-85-01877

- INCREMENTAL EXPANSION BY REPLICATION OF EXISTING UNITS AND FUNCTIONS
- ADDITION OF NEW SYSTEMS AND FUNCTIONS
- INCORPORATION OF ADVANCED TECHNOLOGY
- REPLICATION OF ENTIRE SPACE STATION AS A UNIT

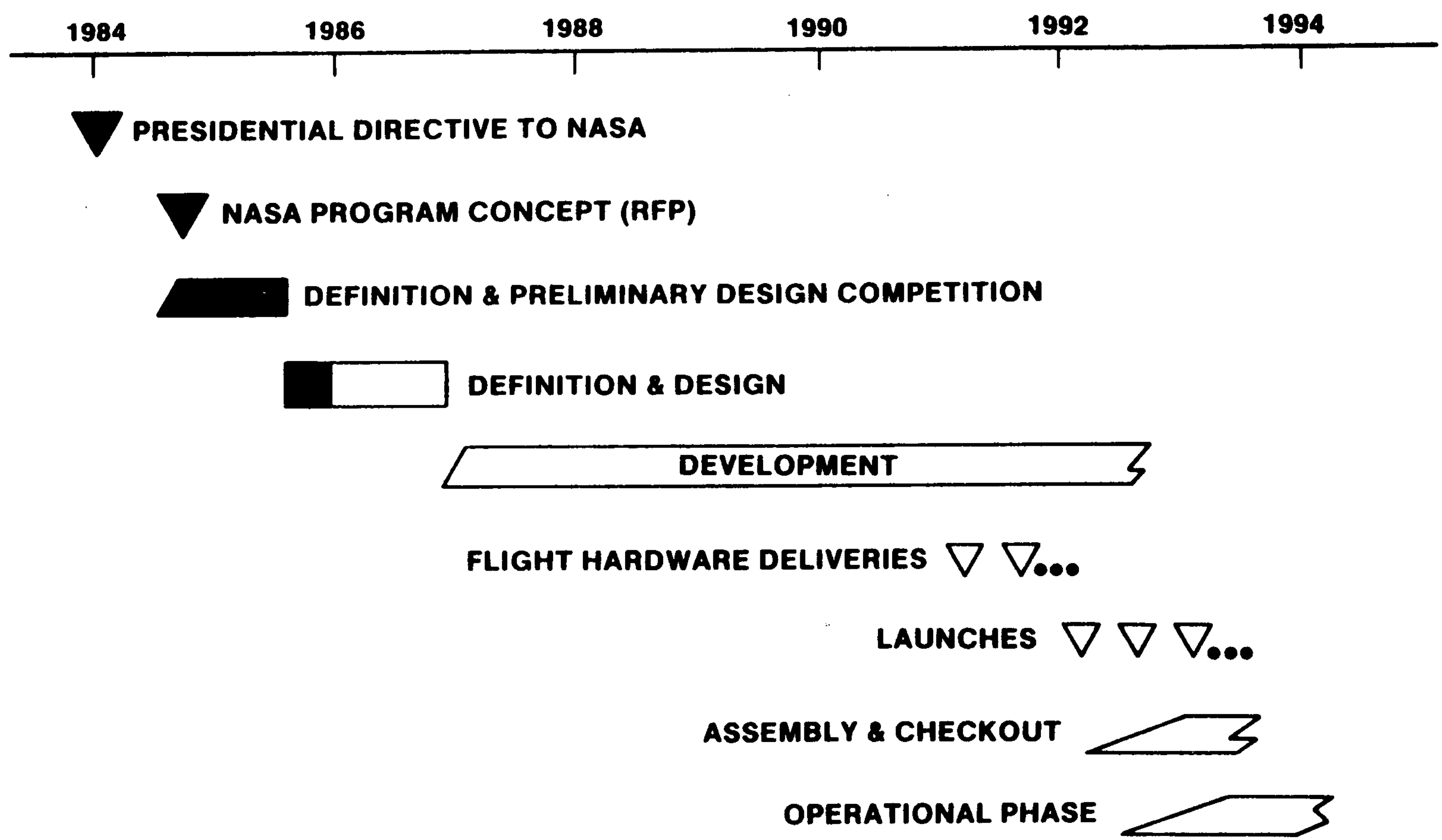


CORE PLATFORM

NASA

S-85-01851

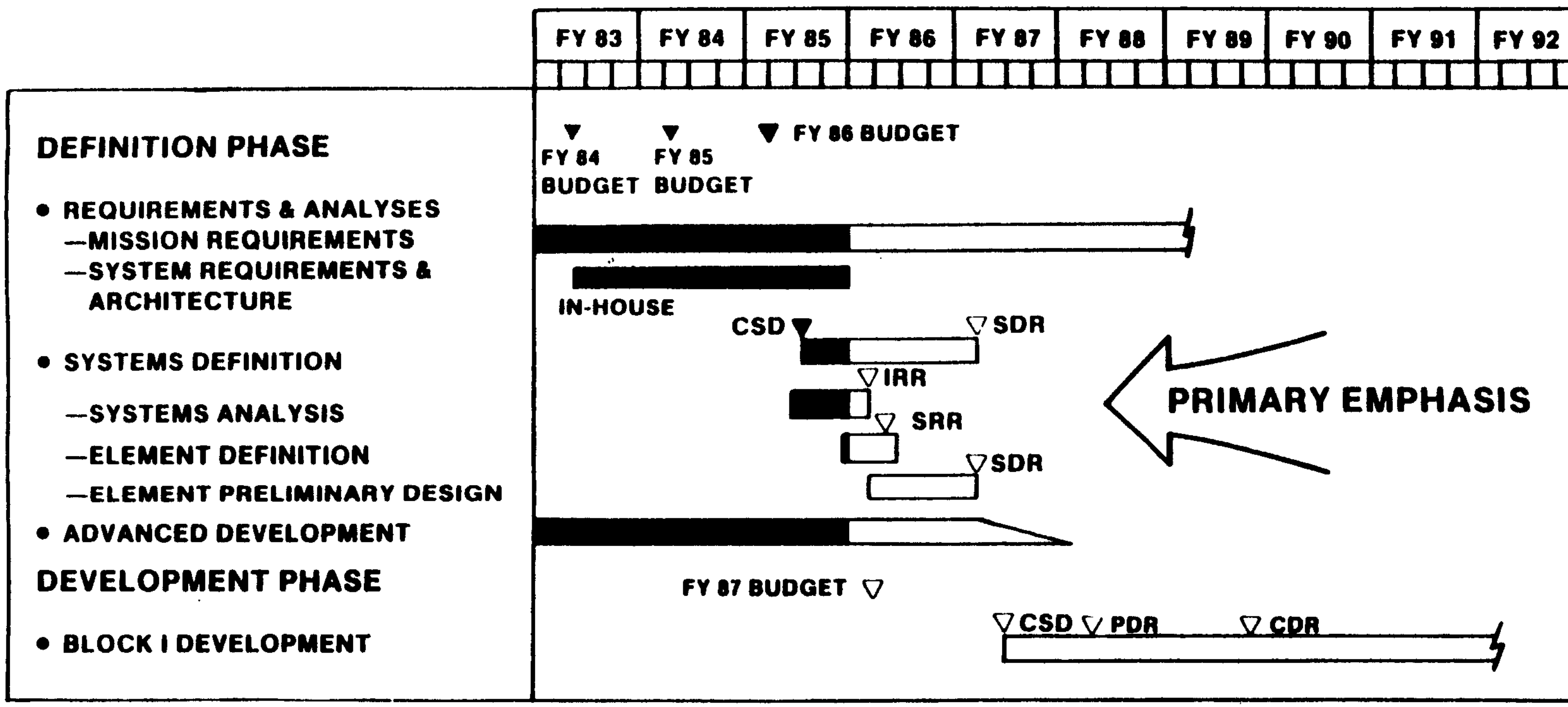
Space Station Program Milestones



NASA

S-84-04254H

Space Station Planning Schedule



CSD — CONTRACT START DATE
CDR — CRITICAL DESIGN REVIEW
IRR — INTERFACE REQUIREMENTS REVIEW
BUDGET — PRESIDENT'S BUDGET TO CONGRESS
PDR — PRELIMINARY DESIGN REVIEW
SDR — SYSTEM DESIGN REVIEW
SRR — SYSTEM REQUIREMENTS REVIEW

WORKSHOP OBJECTIVES

James M. Romero

IN—SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

JAMES ROMERO

OCTOBER 8, 1985

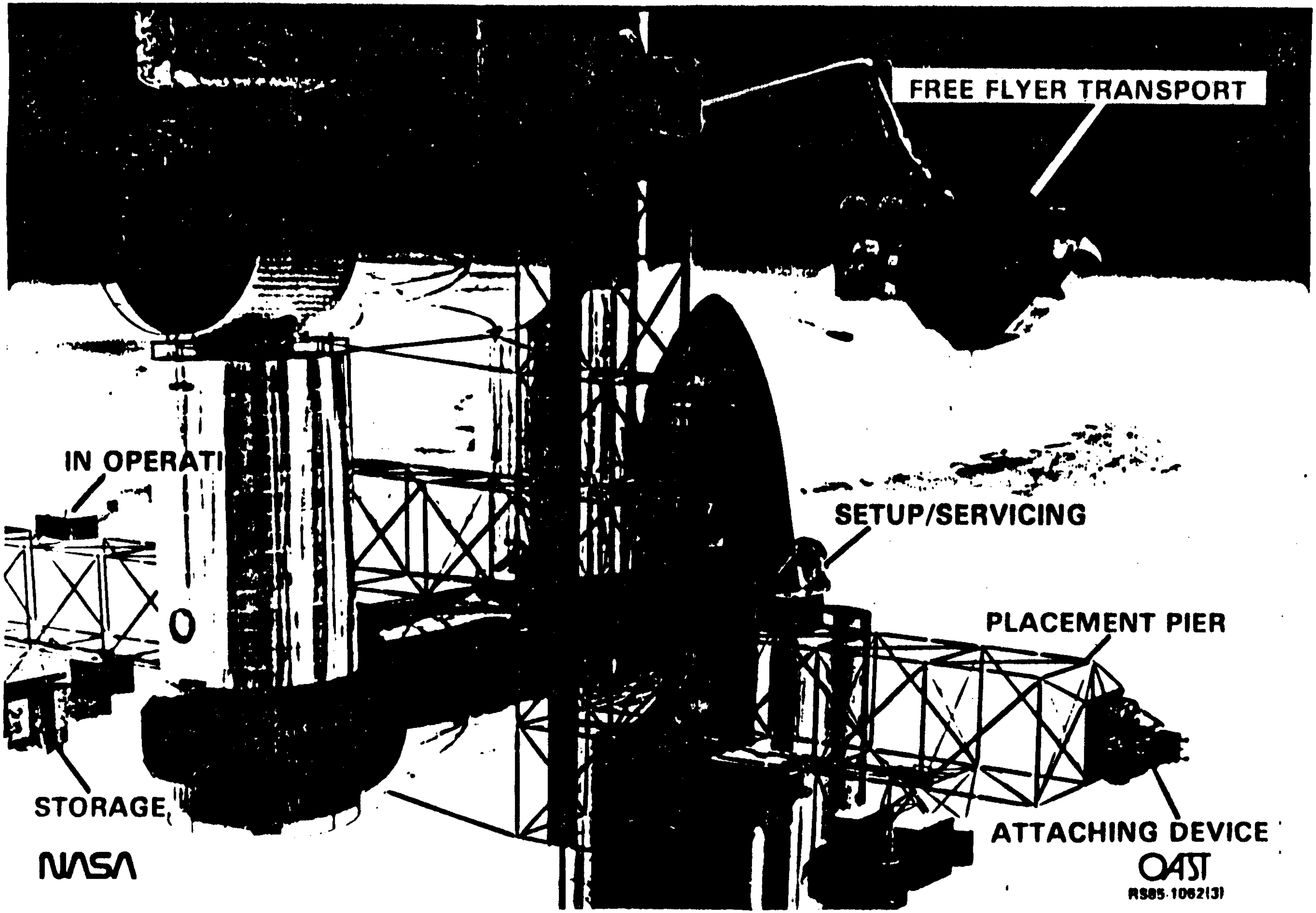
NEED FOR IN—SPACE EXPERIMENTS

- O THE AVAILABILITY OF SPACE SHUTTLE AND SPACE STATION WILL PROVIDE FOR A SIGNIFICANT INCREASE IN IN—SPACE OPERATIONS IN SUPPORT OF NASA, COMMERCIAL, UNIVERSITY, OTHER GOVERNMENT AND INTERNATIONAL INTERESTS

- O ADVANCED AND NEW SPACE TECHNOLOGIES WILL BE REQUIRED TO ENABLE THE BROADEST PRODUCTIVE UTILIZATION OF NEW OPPORTUNITIES IN SPACE

- O APPLICATION OF NEW TECHNOLOGIES (THOSE SENSITIVE TO THE SPACE ENVIRONMENT) WILL BE PACED BY THE CONFIDENCE GAINED THROUGH TEST AND/OR DEMONSTRATION IN SPACE

TECHNOLOGY EXPERIMENTATION



IN—SPACE RESEARCH AND TECHNOLOGY GOAL

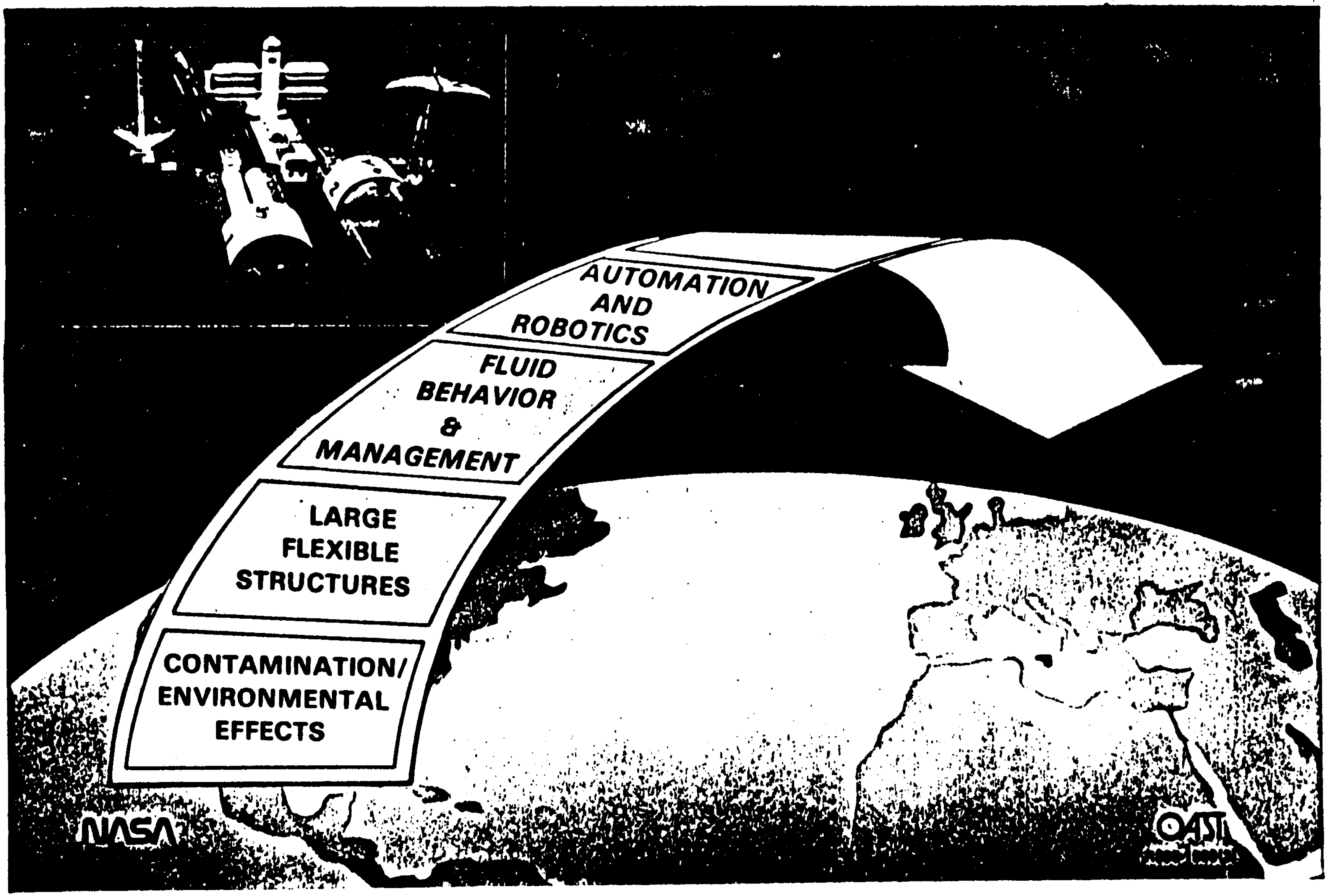
DEVELOP AN IN—SPACE RESEARCH AND TECHNOLOGY PROGRAM UTILIZING SPACE STATION AND OTHER SPACE FACILITIES AS A LOGICAL, EVOLUTIONARY COMPLEMENT TO GROUND—BASED RESEARCH AND TECHNOLOGY

IN—SPACE R&T PROGRAM APPROACH

JOINT PLANNING BY SPACE COMMUNITY TO:

- IDENTIFY IN—SPACE EXPERIMENT NEEDS AND ACCOMMODATION REQUIREMENTS
- DEVELOP A STRONG USER CONSTITUENCY
- ENCOURAGE COOPERATIVE VENTURES
- FACILITATE ACCESS TO SPACE

TECHNOLOGY HORIZONS
IN-SPACE RESEARCH AND TECHNOLOGY



THEME APPROACH

THEMES PROVIDE A PLANNING AND COORDINATION MECHANISM WHICH FOCUS ON FUNCTIONAL CAPABILITIES HAVING BROAD APPLICATION POTENTIAL

- O THEY ARE GOAL ORIENTED/NEED DRIVEN
- O THEY ARE TEMPORAL AND FLEXIBLE –– CAN CHANGE
- O THEY ARE BOUNDED –– CONTENT IS LOGICAL
- O THEY DRIVE ACCOMMODATION REQUIREMENTS WHILE MAINTAINING RELATIVE INSENSITIVITY TO CONTENT SPECIFICS
- O THEY ARE ADVOCABLE/SUPPORTABLE

FLEXIBLE STRUCTURES AND CONTROL

STEP I

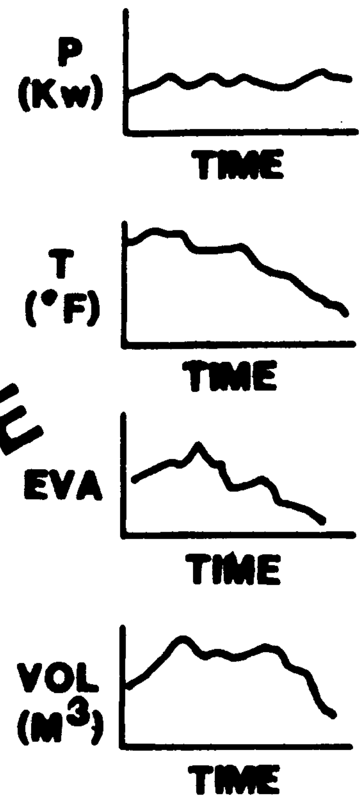
GENERATE LIST OF EXPERIMENTS

1. ADVANCED CONCEPTS
2. ADVANCED SENSORS
3.
4.
5.

EXAMPLE

STEP II

GENERATE HISTOGRAMS OF FUNCTIONAL REQUIREMENTS



STEP III

DEFINE FACILITY TO ACCOMMODATE REQUIREMENTS

TECHNOLOGY THEMES FOR IN—SPACE R&T

- SPACE STRUCTURE DYNAMICS & CONTROL
- ENERGY CONVERSION & THERMAL MANAGEMENT
- FLUID BEHAVIOR AND MANAGEMENT
- CONTAMINATION/ENVIRONMENTAL EFFECTS
- IN—SPACE OPERATIONS

PANEL SUMMARIES

IN—SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

SPACE STRUCTURES (DYNAMICS & CONTROL)

Williamsburg, Virginia
October 8—10, 1985

IN-SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

SPACE STRUCTURE (DYNAMICS AND CONTROL)

SAMUEL L. VENNERI	OAST	CO-CHAIRMAN
GEORGE J. BURMEISTER	BAC	CO-CHAIRMAN
LARRY SILVERBERG	N.C. STATE	EXECUTIVE SECRETARY
MICHAEL CARD	LARC	MEMBER
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EDWARD F. CRAWLEY	MIT	MEMBER
JOHN GARBA	JPL	MEMBER
CLAUDE KECKLER	LARC	MEMBER
ROBERT W. BUCHAN	LARC/SSO	EX-OFFICIO
ROBERT L. CALLOWAY	LARC/SD	EX-OFFICIO

SPACE STRUCTURE
(DYNAMICS AND CONTROL)
SUMMARY
Samuel L. Venneri

The experiments presented to the panel were under five key technology areas as follows:

1. COMPONENT TECHNOLOGY
   - SENSORS
   - ACTUATORS

2. - CONTROL STRUCTURE INTERACTION
   - CONTROL TECHNOLOGY
   - STATION KEEPING
   - MANEUVERS
   - POINTING

3. SPACE STATION DYNAMIC CHARACTERIZATION
   - DYNAMIC MODELLING

4. SPACE STATION CONSTRUCTION TECHNOLOGY
   - MATERIAL BEHAVIOR
   - ASSEMBLY
   - DEPLOYMENT

5. - ADVANCED STRUCTURAL CONCEPTS

To identify technology gaps in the proposed experiments, an experiment/technology matrix was formed for all the experiments proposed. The experiment/technology matrices plus member opinions were used to develop a list of technology gaps. The Committee felt that validation of proposed Space Station IOC structure, including construction techniques, utility integration, and long-term integrity was not adequately addressed. The use of passive damping to solve Station vibration problems was lacking. No experiments involved with in-space loads characterization for the Station were proposed. Consideration of cost-effective hardware was not apparent in proposed experiments. Finally, efforts on structurally embedded sensors/actuators, vibration shape/control devices, and low-frequency isolators were inadequate.

Mass, power, and data requirements were modest. A few experiments required large deployed volumes which the Committee felt were not being addressed by Space Station.

The larger volume experiments gave rise to consideration of what impacts structures experiments might have on Space Station. The Committee felt that Space Station should accommodate the construction and structural testing of future large space systems. Problems induced by this activity were experiment-induced vibration disturbances, large volume envelopes in which to work, and design of an attitude control system to accommodate structural vibration tests. The Committee also felt that the Station design had not been adequately over-designed (scarred) to accommodate a structural development/test facility.

Experiments were examined to indicate their appropriateness for ground, Space Shuttle or Space Station. Originally, the panel had intended to make recommendations on suitability of experiments for ground or flight testing; however, due to shortage of deliberation time and lack of evaluation criteria, the panel was unable to perform this task. Thus, only the sponsors' recommendations for time phasing are presented here.

It appeared that there was a strong interest in long-term durability of components. A Space Station component test facility seemed to be appropriate for such long-term testing activities.

The Actively-Controlled Instrument-Support Truss is an experiment proposed by GSFC to develop technology for platforms which have demanding precision requirements to support multiple instruments. On the Space Station, it is likely that there will be many Control/Structures Interactions experiments including large antennas and robotic or articulated structures. As mentioned previously, the development and test of such structures has significant impact on Space Station design and control.

The Space Station itself can be used as a flight experiment during IOC development and evolution. It would be desirable to have ongoing developments of nondestructive evaluation techniques to monitor the structural health of the Space Station. A longer range problem that needs basic technology is fluid-structure interaction experiments. The Station is expected to have numerous storage tanks of fluids, and the basics of sloshing and dynamic forcing function from fluid dynamics must be understood.

As the Station is constructed, dynamic measurements of its response should be made to confirm math models used in design. A life assessment system could also be installed during this period. After construction, the Station also can be used as a test bed for advanced control experiments. As the Station evolves, the growth Station dynamics can be estimated from growth math models validated by ground tests of a growth Station dynamic model and by selected experiments on Station. For example, components of growth solar dynamics rotating machinery or tank slosh baffles could be evaluated.

To determine the most practical construction technique for Space Station, experiments are ongoing in ground-based neutral buoyancy facilities. NASA's first space construction experiments (ACCESS/EASE) are scheduled for this year. The Committee recommended follow-on Space Station Construction Validation Experiments to ensure that procedures for erection, deployment, and utility integration could be validated. Once the Station was constructed, it would be available as a construction bed on which to assemble large antennas, platforms, and advanced orbital transfer vehicles.

The Committee felt there was a lack of advanced structural concepts for space construction. More effort is needed on design and ground tests of advanced concepts for making structural surfaces, elements and joints, for providing protection from debris and for developing advanced large antennas. Once the Station is operational, it was anticipated that numerous opportunities for making structures in-space might be conceived.

To further encourage development, by industry, the Committee identified critical elements for development. The list below shows sensor, actuator, and computer technology needed for future experiments.

- o High Accuracy Surface Sensor (Multi DOF)
- o Real-Time Photogrametric Concept
- o Mid-Range Momentum Actuators
- o High Speed, High Capacity Flight Computers for CSI
- o High Speed, High Capacity Data Bases

- o Multi-Body Alignment Transfer & Pointing System
- o Relative Alignment Sensor
- o Vibration Actuators
- o Low-Frequency Actuators
- o Optical/Inertial Vibration Sensors
- o Low-G Accelerometer
- o Low-Thruster for Reboost

Because of costs, the Committee felt that it was important to have criteria to measure the value of conducting experiments in space versus on earth. Many of the experiments presented at the workshop were in partial stages of development, and a framework was needed to perform objective screening. Teaming of industry, universities, and NASA should strengthen the creativity and cost-effectiveness of proposed experiments. Finally, a management issue for NASA is to alleviate Shuttle and Space Station integration overhead which is a formidable obstacle to experimenters in universities, industry, and NASA.

NASA should establish a formal review committee for structures, dynamics and control experiments. The committee should quantify IOC Station requirements to ensure that future experiments can be accommodated. It should establish criteria to assist experiment selection and prioritization, and investigate methods to simplify experiment integration. If such a committee existed, the need for future workshops might be questionable, and we could get on with the job of developing a set of affordable and needed Station experiments.

IN-SPACE RESEARCH, TECHNOLOGY, AND

ENGINEERING WORKSHOP

SPACE STRUCTURES

(DYNAMICS & CONTROL)

WILLIAMSBURG, VIRGINIA

OCTOBER 8-10, 1985

STRUCTURES DYNAMICS AND CONTROL

- o KEY TECHNOLOGIES
- o GAPS IN PROPOSED EXPERIMENTS
- o CAPABILITIES REQUIRED ON STATION
  - KEY SUPPORT REQUIREMENTS
- o TIME PHASING
  - TECHNOLOGIES
  - CAPABILITIES
  - EXPERIMENTS
- o JOINT EFFORT OPPORTUNITIES
- o EXPERIMENTAL PROGRAM ISSUES

KEY STRUCTURES DYNAMICS AND CONTROL TECHNOLOGIES

1. COMPONENT TECHNOLOGY
   - SENSORS
   - ACTUATORS
2. CONTROL STRUCTURE INTERACTION
   - CONTROL TECHNOLOGY
   - STATION KEEPING
   - MANUEVERS
   - POINTING
3. SPACE STATION DYNAMIC CHARACTERIZATION
   - DYNAMIC MODELLING
4. SPACE STATION CONSTRUCTION TECHNOLOGY
   - MATERIAL BEHAVIOR
   - ASSEMBLY
   - DEPLOYMENT
5. ADVANCED STRUCTURAL CONCEPTS

EXPERIMENT/TECHNOLOGY MATRIX	Deployment Dynamics	Dynamic Modeling	Articulated Multibody Dynamics	Joint Modeling	Damping Models	Tether Dynamics	Structural Mater (Protective Coa	Passive Damping	Long Life Materials	Environmental Modeling	Disturbance Characterization	Structural Concepts	Low Cost Concepts	ORU Concepts	Integrated Structure/Control	Integrated Sensors				
1. Component Tech. 1. Fiber Optic Sensors - In-Space Appl.																				
2. S/C Strain and Acoustic Sensors																				
3. Docking Sensor																				
4. Attitude Control & Energy Flight Experiment																				
5. Advanced Control Device Technology																				
6. Thermal Shape Control																				
7. Material Durability for Traction Drive									X											
8. Advanced Expt. Pointing and Isolation																				

Figure 4(a)

EXPERIMENT/TECHNOLOGY MATRIX	Attitude Control Devices	Alignment Sensors	Structural Control Actuators	Inertial Sensors	Berthing/Docking Sensors	Shape/Configuration Sensors	Precision Stationkeeping	High Accuracy Pointing Devices	Alignment Techniques	System Identification	Maneuvering Techniques	Orbital Assembly	Test & Verification Sensors	Disturbance Suppression	Articulated System Control	Active Modal Control	Adaptive Control	Shape Control	Distributed Control	Multi-Loop Control	Hierarchical Control
1. Component Tech																					
1. Fiber Optic Sensors - In-Space Appl.				X		X															
2. S/C Strain and Acoustic Sensors						X															
3. Docking Sensor				X																	
4. Attitude Control & Energy Flight Experment	X																				
5. Advanced Control Device Technology	X																				
6. Thermal Shape Control		X																X			
7. Material Durability for Traction Drive																					
8. Advanced Expt. Pointing and Isolation								X													

Figure 4(b)

EXPERIMENT/TECHNOLOGY MATRIX	Attitude Control Devices	Alignment Sensors	Structural Control Actuators	Inertial Sensors	Berthing/Docking Sensors	Shape/Configuration Sensors	Precision Stationkeeping	High Accuracy Pointing Devi	Alignment Techniques	System Identification	Maneuvering Techniques	Orbital Assembly	Test & Verification Sensors	Disturbance Suppression	Articulated System Control	Active Modal Control	Adaptive Control	Shape Control	Distributed Cor	Multi-Loop Control	Hierarchical Control
2. Control/Struc. Interac. Expts.																					
1. COFS Flight Expts.									X	X	X		X		X	X	X	X	X		
2. Flight Dynamics Identification									X												
3. Dynamic Disturbance Control									X	X		X	X	X			X				
4. Distributed Control Experiment									X				X	X							
5. Advanced Adaptive Control									X				X		X						
6. Platform Active Control		X	X														X	X			

Figure 5(a)

EXPERIMENT/TECHNOLOGY MATRIX	Deployment Dynamics	Dynamic Modeling	Articulated Multibody Dynamics	Joint Modeling	Damping Models	Tether Dynamics	Structural Mater (Protective Coats.)	Passive Dampi	Long Life Materials	Environmental Modeling	Disturbance Characterization	Structural Concepts	Low Cost Concepts	ORU Concepts	Integrated Structure/Control	Integrated Sensors				
2. Control/Struc. Interac. Expts. 1. COFS Flight Expts.	X	X																		
2. Flight Dynamics Identification		X																		
3. Dynamic Disturbance Control		X	X																	
4. Distributed Control Experiment		X	X																	
5. Advanced Adaptive Control		X	X																	
6. Platform Active Control		X													X					

Figure 5(b)

EXPERIMENT/TECHNOLOGY MATRIX	Deployment Dynamics	Dynamic Modeling	Articulated Multibody Dynamics	Joint Modeling	Damping Models	Tether Dynamics	Structural Maters. (Protective Coats.)	Passive Damping	Long Life Materials	Environmental Modeling	Disturbance Characterization	Structural Concepts	Low Cost Concepts	ORU Concepts	Integrated Structure/Control	Integrated Sensors
3. Space Station Dynamic Characterization																
1. Space Station Performance Technology Validation	X	X		X	X											
2. Advanced Controls Technology		X		X	X											

Figure 6(a)

EXPERIMENT/TECHNOLOGY MATRIX	Attitude Control Devices	Alignment Sensors	Structural Control Actuators	Inertial Sensors	Berthing/Docking Sensors	Shape/Configuration Sensors	Precision Stationkeeping	High Accuracy Pointing Devices	Alignment Techniques	System Identification	Maneuvering Techniques	Orbital Assembly	Test & Verification Sensors	Disturbance Suppression	Articulated System Control	Active Modal Control	Adaptive Control	Shape Control	Distributed Control	Multi-Loop Control	Hierarchical Control	
3. Space Station Dynamic Characterization																						
1. Space Station Performance Technology Validation										X			X									
2. Advanced Controls Technology										X						X		X				

Figure 6(b)

EXPERIMENT/TECHNOLOGY MATRIX	Deployment Dynamics	Dynamic Modeling	Articulated Multibody Dynamics	Joint Modeling	Damping Models	Tether Dynamics	Structural Matr (Protective Coa	Passive Damping	Long Life Materials	Environmental Modeling	Disturbance Characterization	Structural Concepts	Low Cost Concepts	ORU Concepts	Integrated Structure/Control	Integrated Sensors				
4. Space Const. Technology 1. Advd. Antenna Assem./Perform	X	X																		
2. Precision Optical																				
3. On-Orbit S/C Assembly/Test						X								X						
4. Space Validation of Underwater Testing																				
5. Large Space Antenna	X	X																		
6. Large Space Structure	X	X																		
7. Space Station Modifications																				
8. Structural Assembly Experiments																				

Figure 7(a)

EXPERIMENT/TECHNOLOGY MATRIX	Attitude Control Devices	Alignment Sensors	Structural Control Actuators	Inertial Sensors	Berthing/Docking Sensors	Shape/Configuration Sensors	Precision Stationkeeping	High Accuracy Pointing Devices	Alignment Techniques	System Identification	Maneuvering Techniques	Orbital Assembly	Test & Verification Sensors	Disturbance Suppression	Articulated System Control	Active Modal Control	Adaptive Control	Shape Control	Distributed Control	Multi-Loop Control	Hierarchical Control
4. Space Const. Technology 1. Advd. Antenna Assem./Perform										X		X									
2. Precision Optical										X		X			X				X	X	
3. On-Orbit S/C Assembly/Test												X	X								
4. Space Validation of Underwater Testing												X									
5. Large Space Antenna										X						X		X			
6. Large Space Structure												X									
7. Space Station Modifications												X									
8. Structural Assembly Experiments																					

Figure 7(b)

EXPERIMENT/TECHNOLOGY MATRIX	Deployment Dynamics	Dynamic Modeling	Articulated Multibody Dynamics	Joint Modeling	Damping Models	Tether Dynamics	Structural Mat/ (Protective Coa	Passive Damping	Long Life Materials	Environmental Modeling	Disturbance Characterization	Structural Concepts	Low Cost Concepts	ORU Concepts	Integrated Structure/Control	Integrated Sensors				
5. <u>Advd. Structural Concepts & Fabrication Technologies</u>																				
1. Inflatable/ Rigidifable Structural Element	X						X		X			X								
2. Ion Beam Cold Welding							X													

Figure 8(a)

EXPERIMENT/TECHNOLOGY MATRIX	Attitude Control Devices	Alignment Sensors	Structural Control Actuators	Inertial Sensors	Berthing/Docking Sensors	Shape/Configuration Sensors	Precision Stationkeeping	High Accuracy Pointing Devices	Alignment Techniques	System Identification	Maneuvering Techniques	Orbital Assembly	Test & Verification Sensors	Disturbance Suppression	Articulated System Control	Active Modal Control	Adaptive Control	Shape Control	Distributed Control	Multi-Loop Control	Hierarchical Control	
5. Advd. Structural Concepts & Fabrication Technologies																						
1. Inflatable/ Rigidifable Structural Element												X										
2. Ion Beam Cold Welding												X										

Figure 8(b)

TECHNOLOGY GAPS IN PROPOSED EXPERIMENTS

- VALIDATION OF STATION IOC CONSTRUCTION AND UTILITY INTEGRATION
- VALIDATION OF LONG-TERM STRUCTURAL INTEGRITY
- PASSIVE DAMPING
- IN-SPACE LOADS CHARACTERIZATION
- COST-EFFECTIVE HARDWARE DEVELOPMENT
- STRUCTURALLY-EMBEDDED SENSORS/ACTUATORS
- VIBRATION/SHAPE CONTROL DEVICES
  - SENSORS
  - ACTUATORS
- LOW-FREQUENCY ISOLATION DEVICES

SPACE STRUCTURE (DYNAMICS & CONTROL)
SPACE STATION RESOURCE ACCOMMODATION SUMMARY

TIME FRAME -

MOST EXPERIMENTS AVAILABLE BETWEEN 1992-1994, ALL BY 1997

MASS -

MOST EXPERIMENTS LESS THAN 500 KG
- 2 ARE 1500 KG TO 3000 KG
- 2 ARE 7,000 KG

VOLUME -

MOST REQUIRE LESS THAN 50 M^3 STORED VOLUME
NONE REQUIRE MORE THAN 300 M^3 STORED VOLUME

DEPLOYED VOLUME -

SEVERAL REQUIRE LARGE EXTERNAL VOLUME ENVELOPES 5,000 M^3 - 9,000 M^3

ATTACHMENT -

ALL REQUIRE EXTERNAL ATTACHMENTS

ORIENTATION

GENERALLY NOT AN ISSUE, FEW REQUIRE EARTH, SOLAR, INTERTIAL

POWER -

1.5 KW WILL ACCOMMODATE MOST EXPERIMENTS

DATA -

RATE - 1 MB/S WILL ACCOMMODATE MOST EXPERIMENTS
STORAGE - 1 G BIT WILL ACCOMMODATE MOST EXPERIMENTS

*LARC WILL GENERATE SYNTHESIZED MISSION REQUIREMENTS

IMPACT OF STRUCTURES EXPERIMENTS ON IOC SPACE STATION

- o STATION MUST ACCOMMODATE EXPERIMENT - INDUCED DYNAMIC DISTURBANCE
- o LOCATIONS MUST BE PROVIDED TO ACCOMMODATE EXPERIMENTS WITH LARGE VOLUME ENVELOPES
- o ATTITUDE CONTROL SYSTEM MUST ACCOMMODATE LARGE STRUCTURAL EXPERIMENTS
  - FLEXIBLE STRUCTURES
  - LARGE MASS/INTERIAS
- o IOC STATION DESIGN NEEDS TO BE "SCARRED" FOR STRUCTURAL DEVELOPMENT/TEST FACILITY
  - COMPONENT TECHNOLOGY
  - CSI EXPERIMENTS
  - SPACE CONSTRUCTION
  - ADVANCED STRUCTURAL FABRICATION

TIME PHASING OF EXPERIMENTS

EXPERIMENT	LOCATION					
	GROUND		SPACE			
			SHUTTLE		SPACE STATION	
	SPONSOR	PANEL	SPONSOR	PANEL	SPONSOR	PANEL
1. <u>COMPONENT TECHNOLOGY</u>						
SENSORS SPACECRAFT STRAIN AND ACOUSTIC SENSORS					1992	
FIBER OPTIC SENSORS IN-SPACE APPL.	X				1990	
BERTHING AND DOCKING SENSOR			1987/88			
<u>ACTUATORS</u>						
ATTITUDE CONTROL AND ENERGY EXPERIMENT	X				1992	
ADVANCE CONTROL DEVICE TECHNOLOGY	X				1994	
THERMAL SHAPE CONTROL	X				1992	
<u>TRIBOLOGY</u>						
MATERIAL DURABILITY FOR TRACTION DRIVE					1989	
<u>PROCESSORS</u>						
<u>MECHANISMS</u>						
ADVANCED EXPERIMENT POINTING AND ISOLATION DEVICE					1992	

TIME PHASING EXPERIMENTS

EXPERIMENT	LOCATION					
	GROUND		SPACE			
			SHUTTLE		SPACE STATION	
	SPONSOR	PANEL	SPONSOR	PANEL	SPONSOR	PANEL
2. <u>CONTROL/STRUCTURES INTERACTION</u>						
STRUCTURAL DYNAMICS						
LARGE SPACE REFLECTORS FLIGHT EXPERIMENTS (DEPLOYMENT, PERFORMANCE, ASSEMBLY)					93,94, 96,97	
ENVIRONMENTAL INFLUENCE ON DYN.					1994	
PASSIVE DAMPING						
ZERO "G" EFFECTS						
CONTROL METHODS						
COFS FLIGHT EXPERIMENT			89,90, 91,92			
FLIGHT DYNAMICS IDENTIFICATION					1992	
DYNAMICS DISTURBANCE CONTROL						
DISTRIBUTED CONTROL EXPERIMENTS						
ADVANCED ADAPTIVE CONTROL					1993	
IN-SPACE ACTIVELY CONTROLLED STRUCTURE			89			
DISTURBANCE CONTROL						
ADAPTIVE CONTROL						
DISTURBANCE REJECTION						

Figure 12(b)

TIME PHASING OF EXPERIMENTS

	LOCATION					
	GROUND		SPACE			
			SHUTTLE		SPACE STATION	
EXPERIMENT	SPONSOR	PANEL	SPONSOR	PANEL	SPONSOR	PANEL
3. SPACE STATION DYNAMIC CHARACTERIZATION DYNAMICS OF IOC SYSTEM PERFORMANCE TECHNOLOGY ADVANCED CONTROL TECHNOLOGY					INFINITE SERIES 1992	

Figure 12(c)

TIME PHASING OF EXPERIMENTS

EXPERIMENT	LOCATION					
	GROUND		SPACE			
			SHUTTLE		SPACE STATION	
	SPONSOR	PANEL	SPONSOR	PANEL	SPONSOR	PANEL
4. <u>SPACE CONSTRUCTION TECHNOLOGY</u>						
DEPLOYABLE						
LARGE SPACE STRUCTURES DEMO.					1992	
ERECTABLE						
ADVANCED ANTENNA ASSEMBLY AND PERFORMANCE					1997	
PRECISION OPTICAL SYSTEM ASSEMBLY					1994	
GROUND/FLIGHT CORRELATION						
EVA LARGE STRUCTURE ASSEMBLY			1988		1993	
SPACE BASED CONSTRUCTION						
LARGE SPACE REFLECTORS					93,94, 96,97	
ON-ORBIT SPACECRAFT ASSEMBLY AND TEST					1993	
SPACE STATION MODIFICATIONS					X	
LDR - SPACE STATION IMPACT					1997	
LDR - SPACE STATION IMPACT					1997	
HYBRID CONSTRUCTIONS						
UTILITIES INTEGRATION						

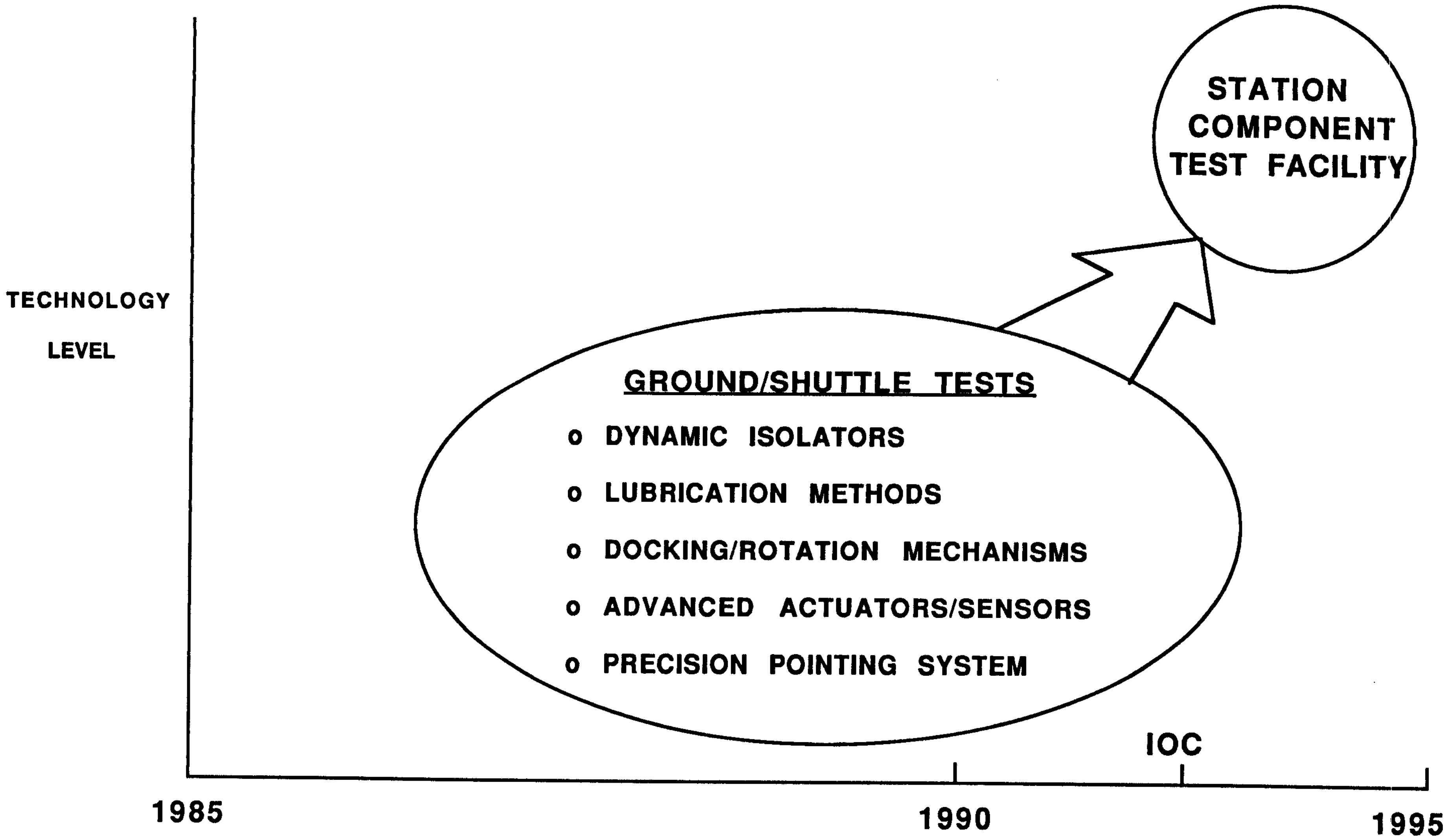
Figure 12(d)

TIME PHASING OF EXPERIMENTS

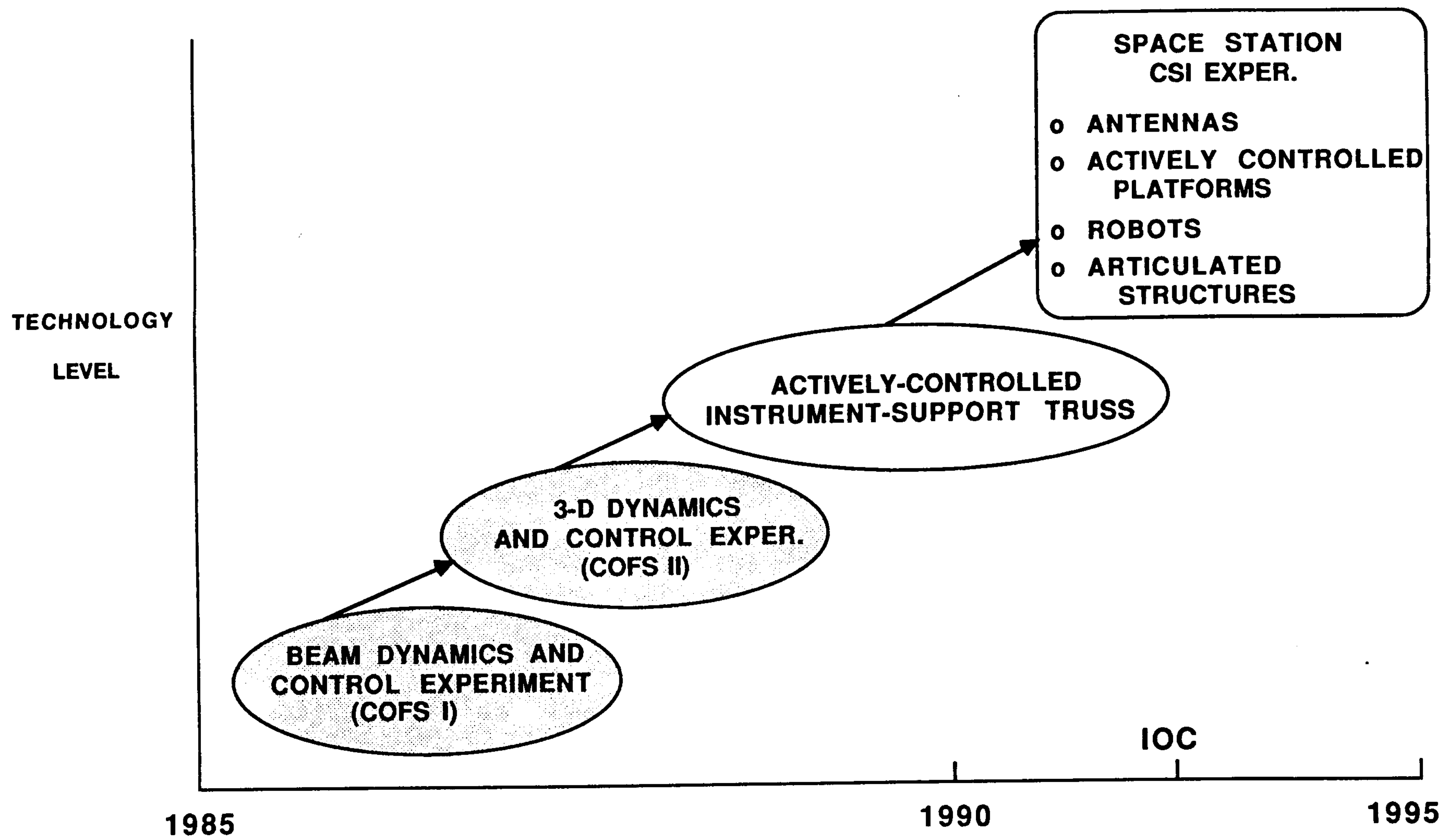
EXPERIMENT	LOCATION					
	GROUND		SPACE			
			SHUTTLE		SPACE STATION	
	SPONSOR	PANEL	SPONSOR	PANEL	SPONSOR	PANEL
5. ADVANCED STRUCTURAL CONCEPT						
INFLATABLES						
INFLATABLES RIGIDIZABLE STRUCTURAL ELEMENTS					1995	
JOINING						
ION BEAM COLD WELDING					X	
ELECTRON BEAM WELDING						
FABRICATION						
NEW STRUCTURAL CONCEPTS FACILITY					1995	
ON-ORBIT COMPOSITE FABRICATION						
VAPOR DEPOSITION						
FORM CONSTRUCTION (GEODESIC FORMS)						
SPACE DEBRIS PROTECTION CONCEPTS						
MICRO METERORITE PROTECTION					1995	

Figure 12(e)

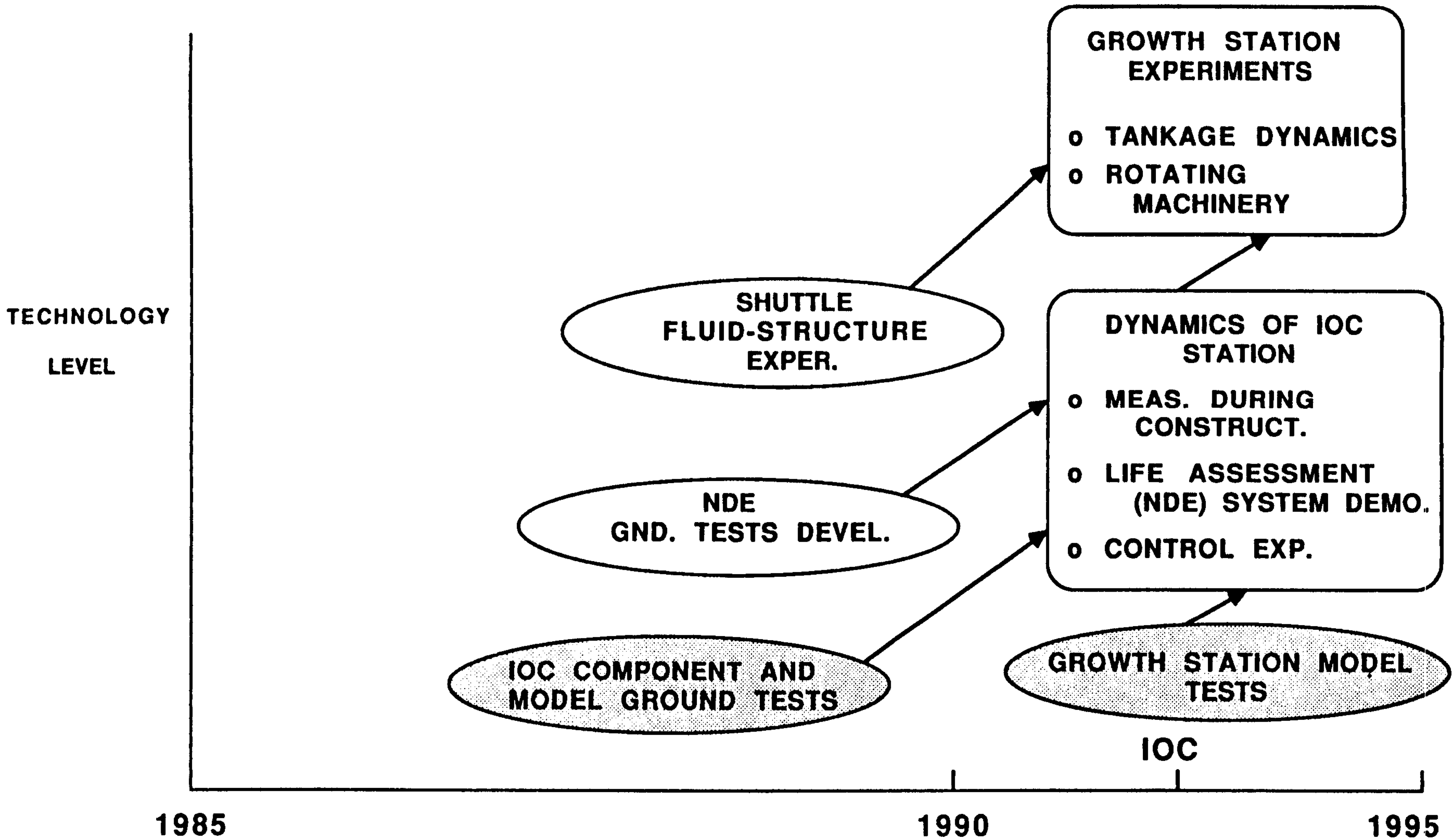
COMPONENT TECHNOLOGY



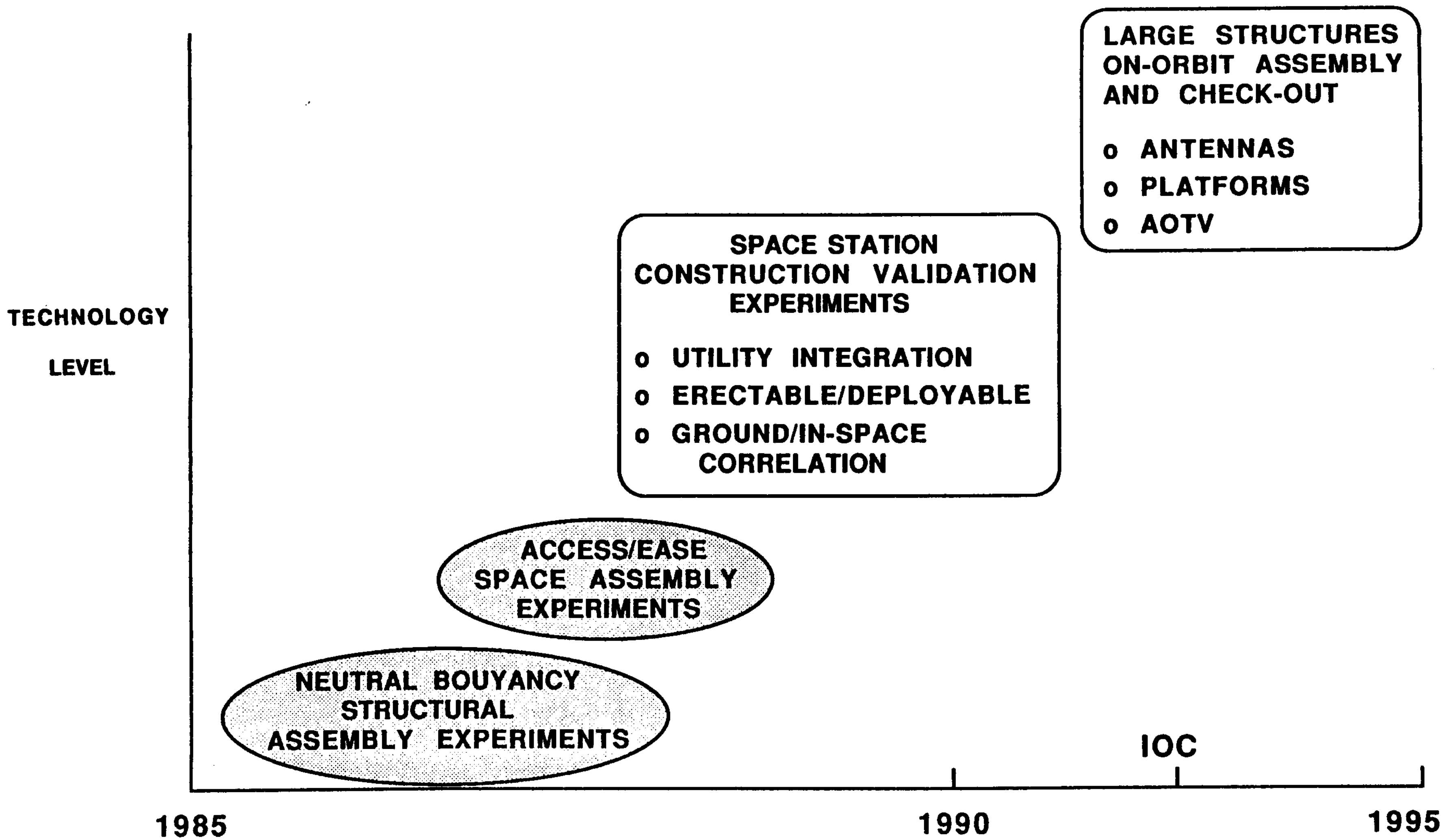
CONTROL/STRUCTURES INTERACTION (CSI)



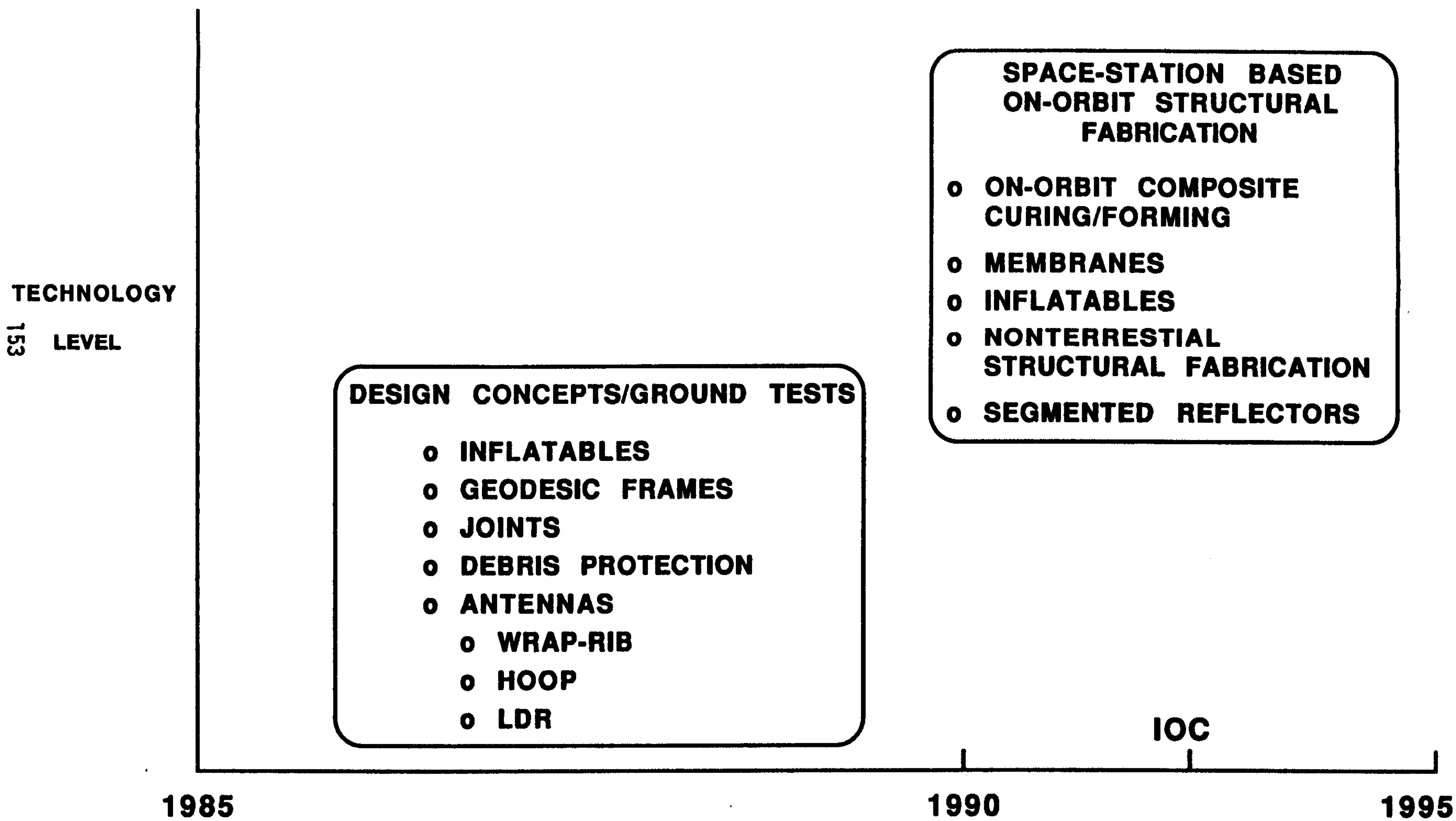
SPACE STATION DYNAMIC CHARACTERIZATION



SPACE CONSTRUCTION TECHNOLOGY



ADVANCED STRUCTURAL CONCEPTS



JOINT EFFORT POTENTIALS

ELEMENT	EXAMPLE SOURCE
o ACTUATORS	
- MOMENTUM DEVICES/ENERGY STORAGE	SPERRY, BENDIX, GE, DRAPER, U. OF MD
- PROOF MASS, LDCM	HARRIS
- PIEZOELECTRIC	
- MAGNETIC BEARING ACTUATORS	SPERRY, BENDIX, U. OF MD
- THERMAL	
o SENSORS	
- INERTIAL (STAR, SUN, RATE, GYROS, ETC)	HONEYWELL, BALL AERO., TELEDYNE, BENDIX, MDAC
- THERMISTORS	
- STRAIN	
- ACOUSTIC	
- RENDEZVOUS & DOCKING	
o MIRRORS	PERKIN ELMER, ITEK
o ANTENNA	LOCKHEED, GD, HARRIS, MARTIN
o BEAM, TRUSS	ASTRO, LOCKHEED, GD, MARTIN
o GIMBALS FOR ARTICULATION	SPERRY, BENDIX, GE
o PAYLOAD/EXPERIMENT EQUIPMENT	DELCO, DEC, IBM
o PAYLOAD/EXPERIMENT EQUPMENT	
- PRECISION POINTING	SPERRY, MARTIN
- ISOLATOR	SPERRY, MARTIN
- ERECTABLE TRUSS	MDAC
- DEPLOYABLE BEAM	ROCKWELL

CRITICAL ELEMENTS NEEDED FOR DEVELOPMENT

- o HIGH ACCURACY SURFACE SENSOR (MULTI DOF)
- o REAL-TIME PHOTOGRAMETRIC CONCEPT
- o MID-RANGE MOMENTUM ACTUATORS
- o HIGH SPEED, HIGH CAPACITY FLIGHT COMPUTERS FOR CSI
- o HIGH SPEED, HIGH CAPACITY DATA BASES
- o MULTI-BODY ALIGNMENT TRANSFER & POINTING SYSTEM
- o RELATIVE ALIGNMENT SENSOR
- o VIBRATION ACTUATORS
- o LOW-FREQUENCY ACTUATORS
- o OPTICAL/INERTIAL VIBRATION SENSORS
- o LOW-G ACCELEROMETER
- o LOW-THRUSTER FOR REBOOST

ISSUES: EXPERIMENTAL PROGRAM ORGANIZATION

- A RIGOROUS CRITERION FOR THE SELECTION OF IN-SPACE TECHNOLOGY EXPERIMENTS MUST BE APPLIED
- A FRAME-WORK TO OBJECTIVELY SCREEN EXPERIMENTS MUST BE DEVELOPED
- THE CREATION OF INDUSTRY/NASA/UNIVERSITY TEAMS MUST BE ENCOURAGED TO ACHIEVE CREATIVITY AND COST EFFECTIVENESS
- A SERIOUS EFFORT MUST BE MADE BY NASA TO ALLEVIATE STS AND SPACE STATION INTEGRATION OVERHEAD FOR EXPERIMENTERS

FUTURE COMMUNITY INTERACTION

- ESTABLISH STRUCTURES, DYNAMICS AND CONTROL EXPERIMENTS REVIEW COMMITTEE
  - QUANTIFY IOC STATION REQUIREMENTS FOR EXPERIMENTS ACCOMMODATION
  - ESTABLISH SPACE EXPERIMENTS SELECTION CRITERIA
  - METHODS TO SIMPLIFY EXPERIMENT INTEGRATION ISSUES
- NEED FOR FUTURE WORKSHOPS?

IN—SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

FLUID MANAGEMENT

Williamsburg, Virginia
October 8—10, 1985

IN-SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

FLUID MANAGEMENT

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FLUID MANAGEMENT SUMMARY

Joseph F. Slomski

Fluid management in space is required for space station, orbit maneuvering vehicles (OMV), orbit transfer vehicles (OTV), scientific payloads, and applications and research satellites. A wide range of fluids are used for these programs and applications; they include cryogens, storable propellants and fluids, superfluid helium and even liquid metals in advanced thermal applications such as solar dynamic power systems.

Orbital fluid management technology includes both fundamental fluid behavior and processes in the low-gravity space environment and fluid management systems which incorporate specific design features to meet on-orbit fluid handling requirements. A very limited data base exists for fundamental fluid behavior in low-gravity. Research areas include free surface behavior, thermal non-equilibrium processes, multi-phase flow, bubbles/droplets/aerosols in vacuum and low-gravity, all aspects of the physics of fluids and special instrumentation/diagnostics for understanding these phenomena. The space station provides an excellent test bed environment for conducting basic research in these technology areas. This data will be useful not only in assisting designers to properly configure fluid systems for space operations but will minimize risks of costly fluid management systems where numerous fluid management technologies are integrated into a somewhat complex integrated system.

Technology is generally available for storable fluid management systems; current systems are working in space, such as the Space Shuttle Orbital Maneuvering System (OMS) and Reaction Control System (RCS) tanks, and numerous communications satellites. Storable fluid transfer and resupply is not proven and a resupply servicer is needed in conjunction with the IOC space station. Special hardware elements such as quantity gaging instrumentation, diagnostics instruments, quick disconnects and fluid couplings require further development.

Much of the detailed technology is not available for cryogenic systems. Some Superfluid helium data has been obtained on a recent Shuttle Spacelab mission, and the IRAS mission involved the flight performance of a superfluid helium Dewar incorporating a porous plug space vent feature. Only small, specialty systems are operational for other cryogens, including the supercritical power/life support and instrument cooling Dewar systems which are not applicable to the large scale required for OTVs and their associated space depots and resupply tankers.

Experimental programs, including systems demonstrations, are needed to provide the appropriate design data base. Scale-up of experimental results to the large space-based systems is an important technology issue, as is long-term space operation. Safety, reliability, and maintainability are important system life cycle cost issues which have a limited data base for reusable system design and operations definition. The timeliness of experimental programs in these technology areas is keyed to the IOC and growth space station concepts and configurations; some fluid management technologies may need to be addressed now to impact Phase C/D space station design or influence SCAR for the growth station. Other technology investigations must be appropriately timed to support customer utilization at the space station and on the co-orbiting platforms.

IN-SPACE RESEARCH, TECHNOLOGY, AND

ENGINEERING WORKSHOP

FLUID

MANAGEMENT

WILLIAMSBURG, VIRGINIA

OCTOBER 8-10, 1985

PANEL 2 - FLUID MANAGEMENT

- ATTENDANCE - OVER 70 PARTICIPANTS
- PRESENTATIONS - 16 PAPERS IN 2 DAYS
- DATA BASE - 16 EXPERIMENTS ADDED TO DATA BASE

TYPES OF FLUIDS

1. STORABLES
2. CRYOGENICS
3. LIQUID HELIUM
4. LIQUID METALS

POTENTIAL INNOVATIVE SPACE TECHNOLOGIES FROM ONE AREA OF FUNDAMENTAL FLUIDS

RESEARCH

RESEARCH AREA

- o STUDY OF LOW AND FINITE VAPOR PRESSURE LIQUID STREAMS FLYING FREE IN SPACE

THINGS STUDIED

- o DISTRIBUTION AND STATE OF THE BREAK-UP PRODUCTS OF LIQUID STREAMS IN SPACE, INCLUDING PROPAGATION CHARACTERISTICS OF THE STREAMS OVER LARGE DISTANCES

WHERE STUDIES

- o INITIALLY ON SHUTTLE
- o DEVELOPING TO LONG SPACE STATION TEST RANGE IN ORDER TO USE LARGE BUT ACCESSIBLE DISTANCES PROVIDED BY THE STATION

POTENTIAL TECHNOLOGIES

- o STRUCTURAL AND SURFACE REFURBISHMENT AND REPAIR
- o LIQUID DROPLET RADIATOR
- o CONTAINERLESS MATERIAL TRANSPORT
- o ULTRA LOW CONTAMINATION SMALL THRUSTERS
- o OTV AEROBRAKE
- o CONSEQUENCES OF CRYOGEN AND OTHER LIQUID LEAKS

FUNDAMENTAL FLUID BEHAVIOR/PROCESSES

PHENOMENA IN LOW GRAVITY

FUNDAMENTAL RESEARCH AREA	(1992) REF IOC SS	(1997) GROWTH SS AND OTV	CUSTOMER UTILIZATION		
			COMMERCIAL	SCIENCE	TECHNOLOGY
FREE SURFACE BEHAVIOR		X	X	X	X
THERMAL NON-EQUILIBRIUM PROCESSES		X	X	X	X
MULTIPHASE FLOW (LIQUID/VAPOR, SOLID/VAPOR, LIQUID METAL, ETC.)	X	X	X	X	X
BUBBLES/DROPLETS/AEROSOLS			X	X	X
PHYSICS OF FLUIDS			X	X	X
SPECIAL INSTRUMENTATION		X	X	X	X

SYSTEMS FLUID MANAGEMENT

SYSTEMS FLUID MANAGEMENT	(1992) REF IOC SS	(1997) GROWTH SS AND OTV	CUSTOMER UTILIZATION		
			COMMERCIAL	SCIENCE	TECHNOLOGY
o LONG TERM STORAGE					
- CRYO AND HELIUM		X	X	X	X
- DEGRADATION IN SPACE		X			
o FLUID TRANSFER AND RESUPPLY					
- STORABLE (PROPELLANTS, OTHER STORABLE FLUIDS)	X	X	X		
- CRYOGENICS (THERMAL CONDITIONING, COMPONENTS)		X	X		
- HELIUM	?	X		X	X
- ADDITIONAL TECHNOLOGIES (INSTRUMENTATION, DIAGNOSTICS, QD'S/ COUPLINGS)	X			X	X
o FLUID LOOPS (SEPARATORS, CIRCULATORS, CONDENSORS)	X	X	X	X	X

EXISTING/PLANNED FLUID SYSTEM FLIGHT EXPERIMENT

- o STORABLES
  - ORBITAL RESUPPLY SYSTEM - (FLEW OCT. 1984)
  - STORABLE FLUID MANAGEMENT DEMO. - (FLEW JAN. 1985, 1986, 1987)
  - ORBITAL SPACECRAFT CONSUMABLES RESUPPLY SYSTEMS - 1990
- o CRYOS
  - CRYOGENIC FLUID MANAGEMENT FACILITY - 1991, 1992, 1993
  - LONG-TERM TEST BED - 1992 (2-5 YEARS)
- o HELIUM
  - SPACELAB SUPERFLUID HELIUM EXP. (FLEW 1985)
  - HELIUM TRANSFER EXP. - 1988
- o INSTRUMENTATION/DIAGNOSTICS/HARDWARE GAGING/FLOW INSTRUMENTATION STUDIES/STORABLE FLIGHT QUICK - DISCONNECT
- o FLUID LOOPS
  - TWO-PHASE SPACE STATION THERMAL MANAGMENT
  - FLUID EXPERIMENT - 1987-1988

RECOMMENDATIONS (NOT RANKED)

- ACCELERATE CRYOGENIC FLUID TECHNOLOGY DEMOS
- MAINTAIN HELIUM TRANSFER EXPERIMENT DATE
- RESOLVE NEEDS FOR:
  - HELIUM DEPOT ON SPACE STATION
  - TWO-PHASE FLOW LOOPS FOR SPACE STATION
- DEVELOP FLUID RESEARCH FACILITY (ALL FLUIDS) FOR SPACE STATION
- DEVELOP FLIGHT TEST, ULTRA-LOW G, DRAG FREE ENVIRONMENT FOR SHUTTLE FLUIDS TESTS NOW.
- EXPAND BASIC, LOW-G, FLUID MANAGEMENT RESEARCH NOW FOR BASIC REEARCH AND TO MINIMIZE RISKS IN MORE COSTLY SYSTEM DEMOS

FUTURE ACTIVITY

RECOMMENDATIONS

- ESTABLISH OAST LOW-G FLUID MANAGEMENT ADVISORY COMMITTEE WITH NASA/INDUSTRY/UNIVERSITY PARTICIPATION
- FOLLOW-UP MEETING IN 6 MONTHS
  - OAST FEEDBACK/RECOMMENDATIONS
  - INTERACTION BETWEEN PANELS
- INPUTS FROM INTEGRATION/SAFETY FOR FLIGHT EXPERIMENTS

GOALS OF PROPOSED OAST LOW-G FLUID MANAGEMENT COMMITTEE

- REVIEW PROGRAMS AND MAKE RECOMMENDATIONS
- DISSEMINATION OF INFORMATION ON EXISTING WORK
- ORGANIZE A SPECTRUM OF FLUID RT&E PROGRAMS
- PROMOTE JOINT UNIVERSITY/INDUSTRY NATIONAL LAB COOPERATION
- PROMOTE INTERACTIONS WITH PROFESSIONAL ENGINEERING SOCIETIES

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IN-SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

SPACE ENVIRONMENTAL EFFECTS

Williamsburg, Virginia
October 8–10, 1985

IN-SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

SPACE ENVIRONMENTAL EFFECTS

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WALT JADERLUND	JOHNSON SPACE CTR.	EX-OFFICIO

SPACE ENVIRONMENTAL EFFECTS SUMMARY

Michael A. Greenfield

This Panel directed itself to reviewing space environmental effects experiments developed to increase the understanding of the service environment and interactions. Overall, the experiments that were presented fell into three major categories. The first were those experiments directed to the development of a space environmental database, taking into account synergistic and multi-parameter effects that cannot be simulated on the ground. The second broad area included those experiments that would allow for validation of ground-based developed models. Only through confidence in these ground-based models can accelerated-life predictions of material response be made accurately. The last area were a group of experiments directed toward exploiting beneficial effects of the space environment such as atomic oxygen cleaning, magnetic altitude control, material modification, etc.

The 26 presented experiments fell into two main areas: those related to environmental definition and those related to the interactive effect of the environment on either the surfaces or bulk properties of materials. The Panel attempted, during this preliminary review of the experiments, to define overlapping technology issues, some measure of cost benefit and time sequencing. It was clear that, in order to maximize the experiment's utility, it was necessary to evaluate experiments as to those that were providing benchmark data; those that would provide an on-going update of the database needed for design; and those that provided mechanistic understandings that would allow for more meaningful ground test and ground test validations. There appeared to be in the group of experiments reviewed a commonality of instrumentation needs. Furthermore, it is felt that not all of the presented experiments actually required in-space Space Station evaluation. Opportunities for either ground test, orbiter flight or free flyers were also evaluated.

It was felt that in order to provide the opportunity for more meaningful environmental-effect experiments on Space Station, certain accommodations would be necessary. Although the needs for power utilities, data collection and transmission lines were not considered to be show-stoppers, there was a need for placement on the Station in areas that were well defined so that experiments could be evaluated as for space environmental effects only and not produce misleading data from contamination. The Panel, working with the audience which was composed of about 50% industry and university people and 50% NASA people, attempted to define what were reasonable short-term achievable goals. It was felt that among these were the ability to characterize the Station environment, develop a common cost-effective instrumentation pool that all experimenters might use and, at least, initially predict material and component performance for the generation of some preliminary engineering data. In the longer term, it was felt that design enhancements for growth Station could be developed; the role of the space environment as a beneficial environment for exploitation could be evaluated; and improvements in the long-term reliability of components could be achieved.

IN-SPACE RESEARCH, TECHNOLOGY, AND

ENGINEERING WORKSHOP

SPACE

ENVIRONMENTAL

EFFECTS

WILLIAMSBURG, VIRGINIA

OCTOBER 8-10, 1985

PHILOSOPHY FOR IN-SPACE ENVIRONMENTAL EFFECTS EXPERIMENTS

- o DEVELOP SPACE ENVIRONMENT ENGINEERING DATA BASE
  - SYNERGISTIC EFFECTS/MULTI-PARAMETER EFFECTS
  - NOT SIMULATABLE ON GROUND
- o VALIDATE GROUND BASED EXPERIMENTS/MODELS
- o EXPLOIT BENEFICIAL EFFECTS
  - ATOMIC OXYGEN CLEANING
  - MAGNETIC ATTITUDE CONTROL
  - TETHER EFFECTS
- o DISCOVER NEW APPLICATIONS
  - ENGINEERING TECHNOLOGIES
  - SCIENTIFIC ADVANCEMENT
  - COMMERCIAL PAYOFFS

MAJOR EXPERIMENTAL AREAS

ENVIRONMENT

DEFINITION

- NATURAL
- INDUCED

INTERACTION EFFECTS

SURFACE

- DEGRADATION OF MATERIALS PROPERTIES
- OPTICAL/THERMAL/MASS LOSS

BULK

- ELECTRONICS
- BIOTECHNOLOGY

PANEL 3: WORKSHOP PRESENTATION SCOPE

	EXPERIMENT CATEGORIES			
	ENVIRONMENTAL DEFINITION		INTERACTION EFFECTS	
ENVIRONMENT	NATURAL	INDUCED	EXTERNAL	INTERNAL
MAG. GRAV., ELEC. FIELDS			X	X
EMI	O	X	X	O
PLASMA	X	X	X	
PARTICULATE RADIATION	X			X
SOLAR EM RADIATION			X	
CONTAMINATION	X	X	X	X
MICROMETEROID/DEBRIS		O	X	
ATMOSPHERIC INTERACTIONS	X	X	X	

X: ADDRESSED IN WORKSHOP

O: NOT COVERED IN WORKSHOP, BUT NEEDED

METHODOLOGY FOR EXPERIMENT DEFINITION

- DEFINE OVERLAPING TECHNOLOGY ISSUES
- COST BENEFIT ANALYSIS/ENGINEERING UTILITY
- SEQUENCING
- TRANSITION TO USER COMMUNITY

MAXIMIZE EXPERIMENT UTILITY

- o BENCHMARK EXPERIMENTS
- o ON-GOING DATA BASE UPDATE
- o FEED DESIGN GUIDELINES
- o DEVELOP MECHANISTIC UNDERSTANDING
- o INSTRUMENTATION COMMONALITY AND FACILITY SELECTION

COMMONALITY OF INSTRUMENTATION

INSTRUMENTATION (TOOL BOX)	EXPERIMENTAL CATEGORIES			
	ENVIRONMENTAL		EFFECTS	
	NATURAL	INDUCED	EXTERNAL	INTERNAL
GAS PHASE	X	X	X	X
SURFACE			X	X
PLASMA	X	X	X	X
RADIATION	X	X	X	X
MECHANICAL PROPERTIES			X	X
DATA ACQUISITION	X	X	X	X

EXPERIMENTAL FACILITY FOR SPACE ENVIRONMENT EFFECTS

	ADVANTAGES	COMMENTS
GROUND	o CONTROLLED ENVIRONMENT o DETAILED STUDIES o LOWER COST	o NOT TOTAL ENVIRONMENTAL TEST
ORBITER	o MANY FLIGHT OPPORTUNITIES o TOTAL ENVIRONMENT	o OPERATIONS MUST BE CONTROLLED o SHORT MISSIONS
FREE FLYER	o GREATER VARIETY OF SPACE ENVIRONMENTS o CONTROL OF INDUCED ENVIRONMENTS o LONG EXPOSURES	o FEWER OPPORTUNITIES o SAMPLE RECOVERY DIFFICULT
SPACE STATION	o TOTAL ENVIRONMENT o LONG EXPOSURES WITH ACCESS TO SAMPLES o ON-ORBIT INSTRUMENTATION/DATA ANALYSIS o ALLOWS MODEL VALIDATION	o INDUCED ENVIRONMENT MUST BE MINIMIZED

SPACE STATION ACCOMMODATIONS FOR ENVIRONMENTAL EFFECTS EXPERIMENTS

LOCATIONS ON STATION

- o "CLEAN" ZONES/NATURAL ENVIRONMENT DEFINITION
  - NO STATION EFFLUENTS
  - NO ELECTROMAGNETIC EMISSIONS
  - ADEQUATE STRUCTURAL SUPPORT
- o REGIONS INSIDE AND NEAR MODULES/INDUCED ENVIRONMENTAL EFFECTS
- o ATTITUDE CONTROL

UTILITIES

- o POWER ($\leq$2 KW AVG.)
- o MODEST COOLING
- o ELECTRICAL GROUNDS
- o CONSUMABLES
  - CRYOGENIC FLUIDS
  - GASES

DATA COLLECTION/TRANSMISSION

- o LONG TERM, LOW RATES

OPERATIONS AND MAINTENANCE

- o EVA
- o ROBOTICS
- o OPERATIONS SCHEDULE/LOG

ACHIEVABLE GOALS

SHORT TERM

- CHARACTERIZE THE STATION ENVIRONMENT
- DEVELOP COMMON, COST EFFECTIVE INSTRUMENTATION POOL
- PREDICT MATERIALS AND COMPONENT PERFORMANCE
- ENGINEERING DATA BASE

LONGER TERM

- DESIGN ENHANCEMENTS FOR GROWTH STATION
- BENEFICIAL EXPLOITATION OF SPACE ENVIRONMENT
- IMPROVED LONG TERM RELIABILITY OF COMPONENTS
- CONTINUALLY UPDATED DATA BASE

THE NEXT STEP

- OVERALL TOP DOWN STRUCTURED GUIDELINES AND MILESTONES FOR PARTICIPATION
- DESIGNATE OAST ADVOCATE
- FORMALIZE INFORMATION EXCHANGE
- ESTABLISH AN EXPERIMENT COORDINATION OVERSIGHT TEAM
- ESTABLISH WORKING GROUPS IN KEY AREAS
- DEVELOP/IMPLEMENT INDUCEMENT PROGRAM

IN—SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

ENERGY SYSTEMS & THERMAL MANAGEMENT

Williamsburg, Virginia
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IN-SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

ENERGY SYSTEMS & THERMAL MANAGEMENT

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ENERGY SYSTEMS AND THERMAL MANAGEMENT

Summary

Earl VanLandingham

To date, the largest space power systems in use have been in the range of 10 kilowatts. Technology is now being developed for the I.O.C. space station at 75 KW, with growth versions being planned at 300 KW and higher. In D.O.D., spacecraft requiring power levels above a MW are being considered. This move to vastly increase power levels has resulted in a technology need for power systems capable of efficiently producing these high power levels with long life and low cost. Solar dynamic and nuclear power systems offer promise to initially meet these increased power requirements. In the longer term, innovative technologies such as laser power transmission may enhance the ability to provide substantial power. With the higher power levels, and the advent of extended space science missions and space manufacturing comes the requirement to both use and reject heat in quantities that are orders of magnitude higher than that of present systems. Many of the new designs being considered and the long term nature of the energy and thermal systems raise the question of the need for in-space experiments.

The Energy Systems and Thermal Management Panel reviewed the proposed experiments. Recognizing that most of the experiments were at the ideal level and minimal technical detail was available, the following general observations were made: much of the proposed experimental effort could be conducted on the ground; many of the proposed experiments were more appropriate for shuttle flights; some experiments because of size or other factors such as safety could not reasonably be conducted on the shuttle or station. In the opinion of the committee, the flight experiments fell into four categories.

(1) Confidence - generally system level tests.

(2) Unique Technology Issues - component level tests to answer a question of how a particular subsystem might operate in zero g.

(3) Development of Fundamental Understanding - Laboratory-type experiments to establish fundamental data needed design or perhaps more likely optimize the design of space power systems. An example of this is the cyclic heat transfer characteristics of two phase materials (particularly solid/liquid) in zero g.

(4) Long-Term Exposure - Atomic Oxygen, Space Plasma, etc.

The panel suggested that consideration be given to the development of a space station based general purpose power/thermal test facility, that would provide power, heat source, instrumentations and controls, data storage, etc. and the characteristics of which would be both known to and suitable for use by the power community. Experiments to address confidence, and unique technology issues need to be further defined and addressed on a case by case basis.

In addition to defining a need for a general purpose test facility, the panel recommended that greater participation by industry, universities and DOD in the definition of experiments is needed. Also, consideration should be given to combining experiments across themes and finally the space station should be instrumented for data purposes.

IN-SPACE RESEARCH, TECHNOLOGY, AND

ENGINEERING WORKSHOP

ENERGY SYSTEMS

&

THERMAL MANAGEMENT

WILLIAMSBURG, VIRGINIA

OCTOBER 8-10, 1985

ENERGY SYSTEMS AND THERMAL MANAGEMENT

GENERAL OBSERVATIONS

- MUCH OF PROPOSED EXPERIMENTAL EFFORT COULD BE CONDUCTED ON THE GROUND
- MANY PROPOSED EXPERIMENTS WERE APPROPRIATE FOR PRECURSOR SHUTTLE FLIGHT
- SOME EXPERIMENTS WERE NOT SUITED FOR SHUTTLE OR SPACE STATION
- MOST EXPERIMENTS WERE AT THE "IDEA" LEVEL -- MINIMAL TECHNICAL DETAIL
- TWO FUNDAMENTAL RESEARCH AREAS WERE IDENTIFIED AS REQUIRING SPACE FLIGHT
  - PHASE CHANGE/HEAT TRANSFER PHENOMENA IN ZERO-G
  - ENVIRONMENTAL EFFECTS
- ADVANCED POWER AND THERMAL SYSTEMS WILL REQUIRE IN-SPACE EXPERIMENTAL SUPPORT

ENERGY SYSTEMS AND THERMAL MANAGEMENT

DRIVERS FOR IN-SPACE EXPERIMENT

- o CONFIDENCE
  - SYSTEM LEVEL TESTS
- o UNIQUE TECHNOLOGY ISSUE
  - COMPONENT TESTS
- o DEVELOPMENT OF FUNDAMENTAL UNDERSTANDING
  - LAB EXPERIMENTS
- o LONG-TERM EXPOSURE

ENERGY SYSTEMS AND THERMAL MANAGEMENT

MISSING INPUTS

- COMPLETE REQUIREMENTS FROM INDUSTRY, UNIVERSITIES AND GOVERNMENT AGENCIES
- COMPREHENSIVE EXPERIMENT PLANS
- ADVANCED SYSTEM CONSIDERATIONS

ENERGY SYSTEMS AND THERMAL MANAGEMENT

KEY TECHNOLOGY ISSUES

PERFORMANCE TESTING

- o COMPONENTS/SUBSYSTEM
- o SYSTEMS

ENVIRONMENTAL FACTORS

- o ATOMIC OXYGEN
- o SPACE PLASMA
- o MICROMETEOROIDS

FUNDAMENTAL PHENOMENA

- o THERMAL TRANSPORT
  - PHASE CHANGE SYSTEMS
- o THERMAL STORAGE
  - SOLID/LIQUID CONTAINMENT
  - HEAT FLOW MANAGEMENT

ENERGY SYSTEMS AND THERMAL MANAGEMENT

REQUIREMENTS FOR ADVANCED POWER/THERMAL SYSTEMS EXPERIMENT FACILITY

- GENERAL PURPOSE
  - EXPLORE FUNDAMENTAL RESEARCH PHENOMENA
  - INVESTIGATE ADVANCED TECHNOLOGY
  - PERFORM ENGINEERING EXPERIMENTS
- USER FRIENDLY
  - VERSATILE
  - FLEXIBLE
  - READILY AVAILABLE
- CAPABILITIES (STRAWMAN UP TO 5 KW)
  - POWER
  - HEAT SOURCE
  - HEAT SINK
  - LOAD BANK
  - INSTRUMENTATION/CONTROLS
  - DATA STORAGE & PROCESSING
  - ATTACHMENT POINTS (INTERNAL & EXTERNAL)
  - ISOLATED AREA(S)
  - IVA
  - EVA

ENERGY SYSTEMS AND THERMAL MANAGEMENT

RECOMMENDATIONS

- OBTAIN ADDITIONAL INPUT TO COMPLETE SPACE STATION EXPERIMENTS DEFINITION
  - INDUSTRY
  - UNIVERSITIES
  - GOVERNMENT
- COMBINE EXPERIMENTS WITHIN/ACROSS THEMES -- INTEGRATE TEST FACILITIES
- DEFINE CAPABILITIES REQUIRED FOR GENERAL PURPOSE ADVANCED POWER/THERMAL SYSTEMS TEST CAPABILITY
- INSTRUMENT SPACE STATION FOR DATA PURPOSES

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IN–SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

INFORMATION SYSTEMS

Williamsburg, Virginia
October 8–10, 1985

IN-SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

INFORMATION SYSTEMS

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INFORMATION SYSTEMS SUMMARY

Bruce A. Conway

The Information Systems theme subpanel was established as a separate part of Panel 5A of the In-Space Operations Theme, in order to 1) provide for additional consideration and emphasis of the information systems areas of sensors, computers/data systems, and communications, and 2) conduct an in-depth review of automation and robotics.

Inputs in the form of reports and oral briefings on 16 technology development experiments pertinent to this theme were reviewed and assessed. The panel then defined a set of objectives for the theme area. In setting forth a set of objectives/capabilities needed to permit technology validation (for in-space application) in the three disciplines of information systems, several gaps in requirements and proposed thrusts were identified. These omissions/gaps were identified by examining OAST's "National Missions for Technology Focus" (supplemented by DoD, commercialization, and international considerations) and projecting a time-ordered series of required capabilities in information systems for various missions. In several cases, particularly in the computer/data systems discipline, no space station-related missions proposed would achieve these required capabilities. Also, some capabilities had not been identified and were only defined after examination of the major mission drivers. The rationale for in-space technology development and verification was discussed and summarized by the panel, and an "accommodations impact" on the space station through the information systems technology capability development was assessed. In the station accommodation assessment, three issues were raised for consideration by space station configuration and systems planners. Finally, recommendations for space station and technology development mission implementation were developed, based on the desired technology capabilities, experiments/missions already proposed, and perceived gaps in the capability/experiment definitions.

Primary objectives defined by the panel, which applied to the three disciplines are 1) to develop/evolve/enable new sensing, data, and communications options, and 2) to enable the in-space characterization, qualification, and optimization of information systems elements. Technology issues or gaps include the lack of clear user identification of data capacities (rates and storage requirements) and the uncertainty in needs for spacecraft environment sensing. In addition, input identifying DoD, other NASA, and commercial activities or potential involvements was also lacking.

The rationale for developing and verifying through in-space experiments, the technology capabilities necessary in information systems includes the long duration exposure of electronic systems in the unique radiation environment (of significance to the substantial electronics portion of the information systems), and zero-gravity effects (of major concern in the utilization of large antenna structures in communications and microwave remote sensing applications). Also, the panel noted the lack of advocacy to test electronic systems in space prior to operational usage. They stated that credibility of in-space demonstrations is crucial to technology acceptance by potential users/appliers.

In developing technology capability objectives and assessing their achievement through in-space research, technology and engineering, three in-space station accommodation issues related to the information systems technology areas were raised: 1) a need to extend the OMV's capabilities; 2) the requirement to have separate, dedicated technology facility modules; and 3) the need for identifying and reserving dedicated experiment locations on the space station structure. Other accommodation impacts were identified, but are expected to prove tractable. The accommodation issues led to recommendations for consideration by space station configuration and systems planners:

1. Extend OMV capabilities (range, formation-flying, enhanced technology support equipment attached to OMV).
2. Provide major dedicated technology laboratory facilities (including work stations, specialized equipment and instrumentation).
3. Provide multipurpose technology test sites onboard the station (considering exposure, field-of-view, data links, swept volume, isolation, and growth compatibility).

Recommendations related to the pursuance of technology development missions are as follows:

1. Define "missing" technology missions (including in-space electronics qualification and high capacity data storage/high data rate systems).
2. Review mission timing and applications, on a periodic basis, with projected science, applications, and commercial users.

In summary, in-space research, technology, and engineering appears to be a necessary ingredient in developing advanced capabilities which permit the full utilization of space. This in-space R, T & E is the only mechanism for information systems electronics and large antenna technologies to be effectively developed <u>and</u> verified. Finally, the development of the manned space station provides a unique capability and opportunity to effectively pursue the achievement of the enhanced capabilities required in improved information systems and their applications.

IN-SPACE RESEARCH, TECHNOLOGY, AND

ENGINEERING WORKSHOP

INFORMATION

SYSTEMS

WILLIAMSBURG, VIRGINIA

OCTOBER 8-10, 1985

INFORMATION SYSTEMS

- o OBJECTIVES
- o CANDIDATE MISSIONS
- o MAJOR MISSION DRIVERS
  - SENSOR SYSTEMS
  - COMPUTER SYSTEMS
  - COMMUNICATION SYSTEMS
- o STATION ACCOMMODATION IMPACT
- o ACCOMMODATION ISSUES
- o RECOMMENDATIONS

INFORMATION SYSTEMS

OBJECTIVES

SENSOR SYSTEMS

- ENABLE IN-SPACE CHARACTERIZATION/OPTIMIZATION OF SENSOR SYSTEM ELEMENTS
- DEVELOP/EVOLVE NEW REMOTE SENSING OPTIONS

COMPUTER/DATA SYSTEMS

- PROVIDE IN-SPACE ELECTRONICS QUALIFICATION CAPABILITY
- EVOLVE HIGH-SPEED ONBOARD SIGNAL PROCESSING CAPABILITY
- PROVIDE LARGE CAPACITY ONBOARD DATA STORAGE AND RETRIEVAL CAPABILITY

COMMUNICATIONS SYSTEMS

- ENABLE NEW COMMUNICATION OPTIONS
- PROVIDE CAPABILITY FOR IN-SPACE COMMUNICATION SYSTEMS CHARACTERIZATION/OPTIMIZATION

INFORMATION SYSTEMS

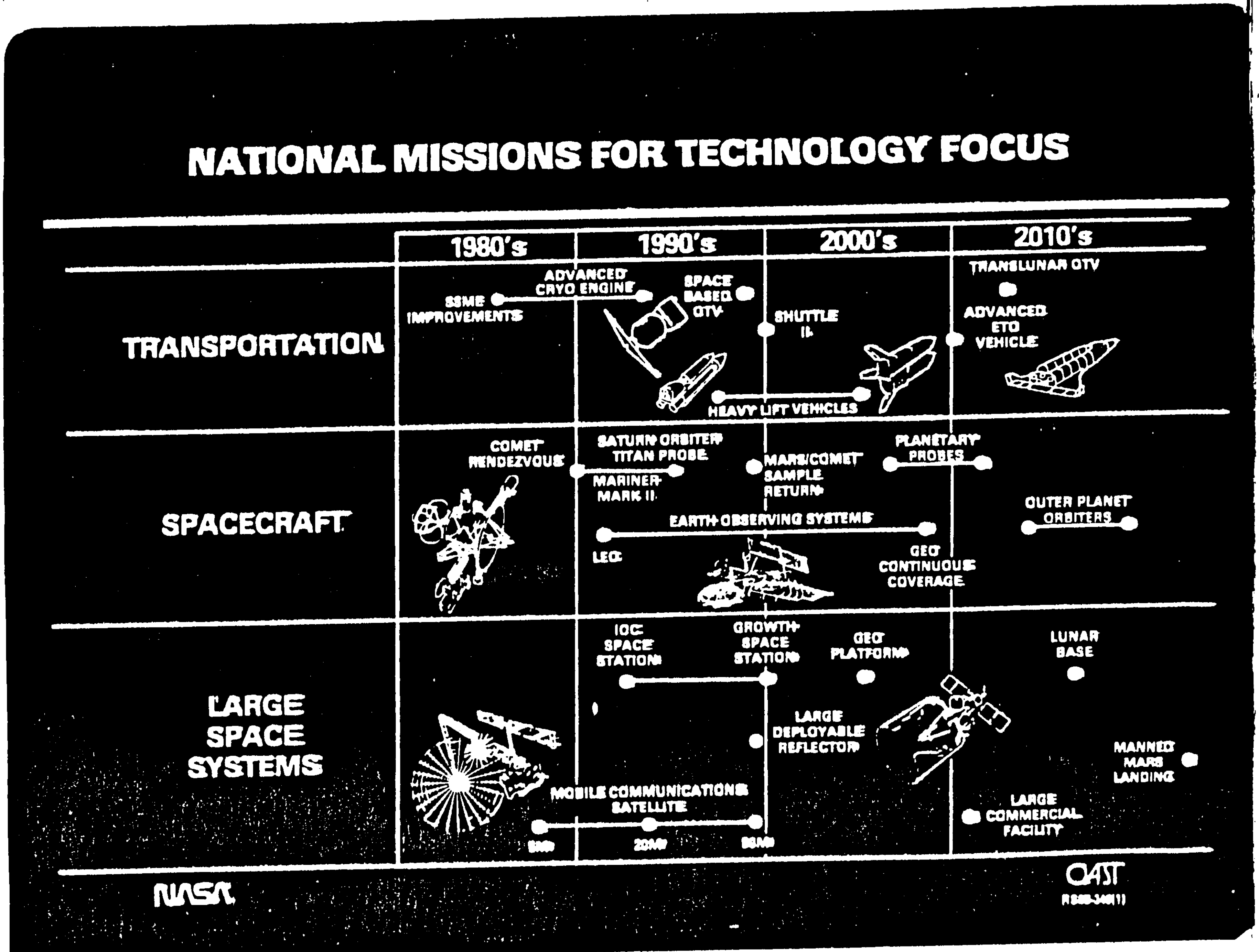
TECHNOLOGY ISSUES/CONCERNS/GAPS

- NO CLEAR IDENTIFICATION OF DATA CAPACITIES - RATES, STORAGE REQUIREMENTS
- S/C ENVIRONMENT SENSING LARGELY OVERLOOKED IN EXPERIMENT PROPOSALS
- APPLICABLE DOD/CODE E/OTHER ACTIVITIES SHOULD BE IDENTIFIED
- COMMERCIAL INVOLVEMENT NEEDS ENHANCING
- NO EXPERIMENTS PROPOSED IN IMAGING SENSORS, IR RADIOMETER AREAS

INFORMATION SYSTEMS
CANDIDATE MISSION

1.	TDMX	MULTI-FUNCTION SPACE ANTENNA RANGE TECHNOLOGY
2.	TDMX	MULTI-FUNCTION MULTI-FREQUENCY SPACE ANTENNA RANGE TECHNOLOGY
3.	TDMX	MASER PRECISION TIME GENERATION
4.		40 - 105 GHZ PROPAGATION EXPERIMENT
5.		HIGH VOLTAGE TWT AMPLIFIER
6.	TDMX - 2224	DEEP SPACE OPTICAL DSN TERMINAL
7.		OPTICAL INTERFEROMETRY SPACECRAFT TRACKING
8.	TDMX - 2221	LASER COMMUNICATIONS AND TRACKING EXPERIMENT
9.	TDMX - 2261	SENSOR SYSTEMS TECHNOLOGY LABORATORY
10.	TDMX - 2366	CO_2 LIDAR WIND MEASUREMENT
11.	TDMX - 2264	MICROWAVE REMOTE SENSING (CO-ORBITING) FREE-FLYER
12.		ADVANCED ORBITING VLBI
13.	TDMX - 2523	ACOUSTIC CONTROL TECHNOLOGY
14.		LASER COMMUNICATIONS
15.		SATELLITE DOPPLER METEROLOGICAL RADAR EXPERIMENT
16.	TDMX - 2216	MANNED OBSERVATION TECHNIQUES

NASA
National Aeronautics and
Space Administration



INFORMATION SYSTEMS

TRANSPORTATION	
ADVANCED CRYOGENIC ENGINE	ACE
SPACE BASED OTV	SOTV
SHUTTLE II	STS
HEAVY LIFT VEHICLES	ALV
TRANSLUNAR OTV	TOTV
ADVANCED ETO VEHICLE	AEV
SPACECRAFT	
SATURN ORBITER, TITAN PROBE	SOTP
LEO EOS	LEOS
GEO EOS	GEOS
MARS/COMET SAMPLE RETURN	MCSR
PLANETARY PROBES	PP
OUTER PLANET PROBES	OPP
LARGE SPACE SYSTEMS	
MOBILE COMMUNICATIONS SATELLITE	MCS
IOC SPACE STATION	ISS
GROWTH SPACE STATION	GSS
LARGE DEPLOYABLE REFLECTOR	LDR
LARGE COMMERCIAL FACILITY	LCF
LUNAR BASE	LB
MANNED MARS LANDING	MML
OTHER	
DOD SUPPORT	DS
COMMERCIALIZATION SUPPORT	CS
INTERNATIONAL SUPPORT	IS

SENSORS

MAJOR MISSION DRIVERS

TECHNOLOGY THRUST		RELATED STATION MISSIONS	ENABLING CAPABILITY	ENHANCING CAPABILITY
IN-SPACE CHARACTERIZATION/OPT.				
IOC +4	SPACE STATION SENSOR CALIBRATION LAB	TDMX-2261, TDMX-2265 TDMX-2266, TDMX-2264, VLBI	LEOS, LCF, MML	SOTV, TOTV, LEOS, GEOS, MCSR, PP, OPP, GSS, DS, CS, IS
NEW REMOTE SENSING OPTION				
IOC	BASIC EARTH OBSERVATION SENSORS	TDMX-2366, TDMX-2264 TDMX-2265	LEOS	LCF, DS, CS, IS
IOC +7	SPACECRAFT ENVIRON-MENT SENSORS (INTERNAL AND EXTERNAL)	TDMX-2523	LB, MML, GSS	TOTV, LB, DS
IOC +2	LARGE APERTURE HIGH FREQUENCY ANTENNA REFLECTOR	TDMX-2264, VLBI	LEOS, GEOS, MCS	GSS, CS, IS
IOC +3	RELATIVISTIC PHENOMENA SENSORS	TDMX-2263		
IOC +5	ADVANCED EARTH OBSERVATION SENSORS	TDMX-2265	GEOS, LEOS	DS, CS, IS

COMPUTER SYSTEMS

MAJOR MISSION DRIVERS

	TECHNOLOGY THRUST	RELATED STATION MISSIONS	ENABLING CAPABILITY	ENHANCING CAPABILITY
o	IN-SPACE ELECTRONICS QUALIFICATION			
IOC +1	CIRCUIT EVALUATION LAB	TBD		ALL MISSIONS
IOC +3	COMPONENT EVALUATION LAB	TBD		ALL MISSIONS
o	HIGH-SPEED ONBOARD SIGNAL PROCESSING			
IOC +2	GIGAFLOP PROCESSOR	TBD	LEOS	GSS
IOC +10	10 GIGAFLOP PROCESSOR	TBD	GEOS	GSS
o	LARGE CAPACITY ONBOARD STORAGE			
IOC	TERRABIT ERASABLE RECORDER	TBD	LEOS	ISS

COMMUNICATIONS SYSTEMS

MAJOR MISSION DRIVERS

TECHNOLOGY THRUST		RELATED STATION MISSIONS	ENABLING CAPABILITY	ENHANCING CAPABILITY
o	IN-SPACE CHARACTERIZATION/OPT.			
IOC	BASIC ANTENNA RANGE	1. TDMX 2211		MCS, LDR, IS
IOC	OPTICAL ANTENNA RANGE	6. TDMX 2224	MCSR, OPP	PP, IS
		8. TDMX 2221		GSS, IS
IOC	COMPONENT TEST FACILITY	4. TDMX ????		LCF,GSS,CS,DS
		5. TDMX ????		LCF,GSS,CS,DS
IOC +2	ADVANCED ANTENNA RANGE	2. TDMX 2212	GEOS	CS, MCS, LDR, IS, DS
o	NEW COMM. OPTIONS			
IOC +2	500 MBps OPTICAL LINK	14. TDMX ????	TDAS	EOS, MCSR
IOC +5	40 TO 100 GHz SPECTRUM UTILIZATION	4. TDMX ????	TDAS	
IOC +6	50M MULTIBEAM REFLECTOR	TDMX 2212	MCS	
IOC +7	4 PI-STER. LOCAL	8. TDMX		GSS
IOC +12	100M DBS ANTENNA	TDMX 2264, TDDMX 2212	EOS	

WHY IN-SPACE?

- LONG EXPERIMENT TIME IN SPACE ENVIRONMENT
  - UNIQUE RADIATION ENVIRONMENT
  - ZERO-G EFFECTS (PARTICULARLY ON LARGE SYSTEMS/ STRUCTURES)
- ATMOSPHERIC TRANSMISSION NEEDED FOR COMM/SENSOR EXPERIMENTS
- OBSERVATIONS EXO ATMOSPHERE REQUIRED
- LARGE SPACE PLATFORM REQUIRED TO SUPPORT LARGE SYSTEMS (E.G. LARGE ANTENNAS)
- EVALUATION/CHARACTERIZATION OF EARTH OBSERVATION SENSORS
- CREDIBILITY OF IN-SPACE DEMONSTRATIONS CRUCIAL TO TECHNOLOGY ACCEPTANCE

STATION ACCOMMODATION IMPACT

- CONTAMINATION
  - RFI, ACOUSTICS, OUTGASSING, ETC.
- LARGE DEPLOYED VOLUME REQUIREMENTS
- EXTREME DATA STORAGE SYSTEM NEEDS
- LINK DATA RATE REQUIREMENTS NEAR TDRSS LIMIT
- GENERALLY MODEST MASS/POWER NEEDS
- CONTROL SYSTEMS CONCERNS
  - ISOLATION, MOMENTUM MANAGEMENT, STRINGENT POINTING, ACTIVE CONTROL, ETC.
- CONSIDERABLE CREW INTERACTION WITH EXPERIMENTS

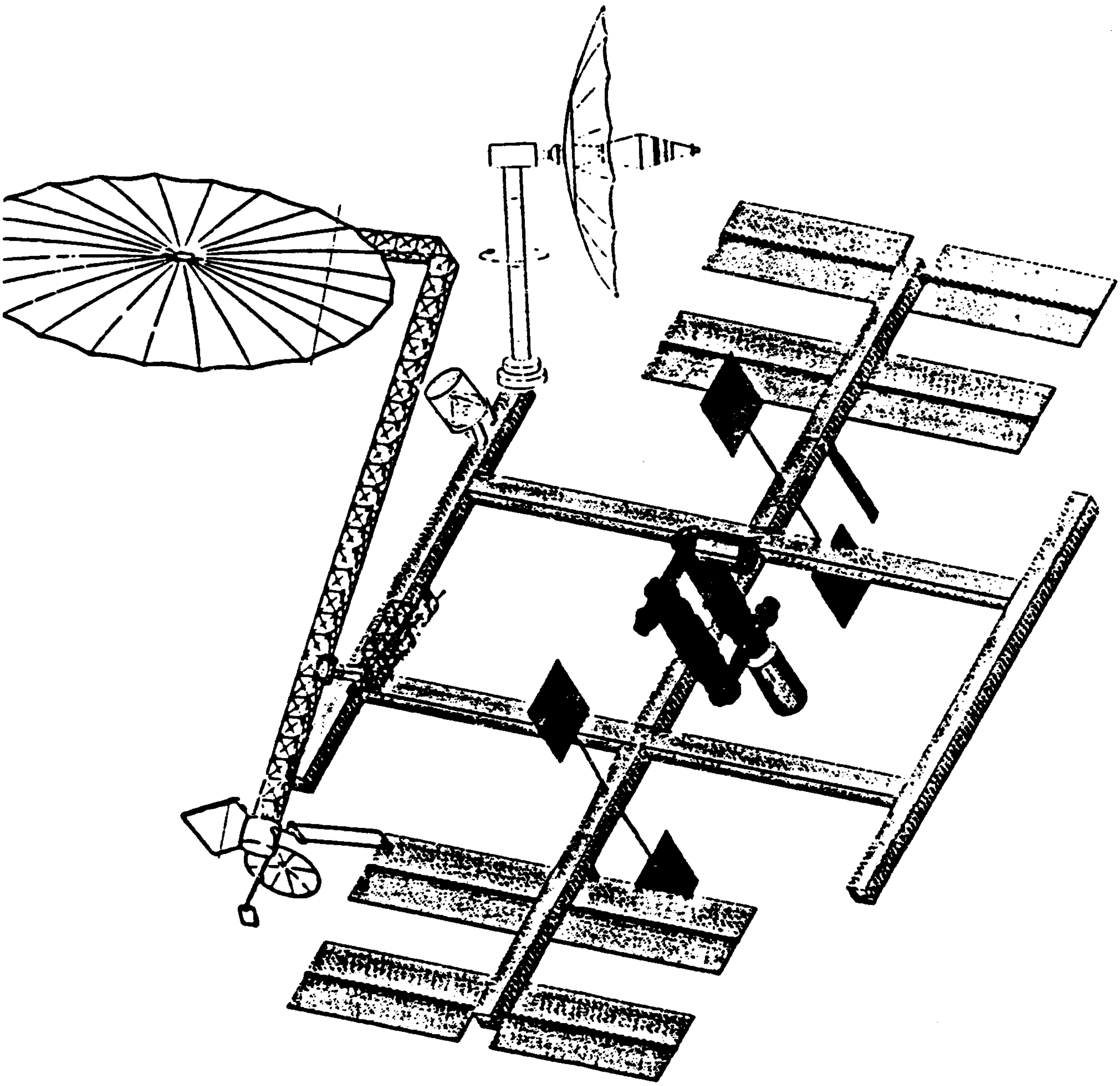
ACCOMMODATION ISSUES

- o NEED TO EXTEND OMV RANGE
- o MAJOR TECHNOLOGY FACILITY MODULE(S) REQUIRED
- o DEDICATED EXPERIMENT LOCATION NEEDED

INFORMATION SYSTEMS

RECOMMENDATIONS - STATION

- PROVIDE MULTIPURPOSE TECHNOLOGY TEST SITES ONBOARD STATION
  - EXPOSURE FOV, SWEPT VOLUME
  - UTILITIES
  - HIGH RATE DATA LINK
  - GROWTH-COMPATIBLE
  - ISOLATION
- EXTENDED OMV CAPABILITIES (OR DEVELOP SMART PLATFORMS)
  - RANGE
  - ENHANCED FORMATION-FLYING
  - OMV-ATTACHED TECHNOLOGY SUPPORT EQUIPMENT
- PROVIDE MAJOR DEDICATED TECHNOLOGY LAB FACILITIES
  - WORK STATIONS
  - SPECIALIZED EQUIPMENT
  - INSTRUMENTATION



INFORMATION SYSTEMS

RECOMMENDATIONS - MISSION

- o DEFINE "MISSING" TECHNOLOGY MISSIONS
  - IN-SPACE ELECTRONICS QUALIFICATION
  - HIGH CAPACITY DATA STORAGE
  - HIGH DATA RATE SYSTEMS
  - 500 MB/S OPTICAL LINK

- o REVIEW MISSION TIMING AND APPLICATIONS WITH PROJECTED USERS
  - SCIENCE, APPLICATIONS
  - COMMERCIAL

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IN-SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

AUTOMATION & ROBOTICS

Williamsburg, Virginia
October 8–10, 1985

IN-SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

AUTOMATION AND ROBOTICS

LEE HOLCOMB	OAST	CO-CHAIRMAN
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AUTOMATION AND ROBOTICS SUMMARY
Lee Holcomb

The Automation and Robotics panel recommended an evolutionary set of in-space robotic capabilities be developed starting with rendezvous and docking (1988), simple satellite servicing (1990), structural assembly (1992), and robotic assistants for IVA (1996), and EVA (2000) operations. During this time frame the nature of robotic capability will evolve from telepresense to supervisory control and ultimately to autonomous operations. The panel felt that in-space related experiments were essential; however, they felt most AI-based systems autonomy capabilities could be demonstrated on the ground.

In-space robotic experiments are needed to evaluate our analytical predictions of zero-G dynamics of mechanical equipment. The result of in-space experimentation would be a design/operational database on telerobotic capability. Experimentation would provided evaluation of the man/machine performance on-orbit and validation of protoflight hardware/software.

A series of experiments were proposed dealing with mobility, dextrous manipulation, supervised/autonomous operation, and evaluation of the man/machine interface. A potential list of experiments was recommended. The attached briefing package lists the experiments proposed and the critical technologies to be evaluated.

A number of accommodation issues were raised. The first and most pressing is the development of "robot friendly" interface for servicing, assembly, and docking. In addition, a "standard" set of utilities need to be defined for interface to mobility systems (RMS, MRMS, OMV, OTV, etc.). A key accommodation issues are the safety constraints for in-space robotic experiments will press beyond current plans for onboard computing and data storage capabilities.

IN-SPACE RESEARCH, TECHNOLOGY, AND

ENGINEERING WORKSHOP

AUTOMATION
&
ROBOTICS

WILLIAMSBURG, VIRGINIA

OCTOBER 8-10, 1985

AUTOMATION AND ROBOTICS

OBJECTIVES/CAPABILITIES

- o VALIDATE ROBOTIC IN-SPACE OPERATIONS CAPABILITY
  - DOCKING - 1988
  - SATELLITE SERVICING - 1990
  - STRUCTURAL ASSEMBLY - 1992
  - IVA ASSISTANT - 1996
  - EVA ASSISTANT - 2000
- o EVOLVE ROBOTIC IN-SPACE OPERATIONS CAPABILITY
  - TELEPRESENCE - 1990
  - SUPERVISORY CONTROL - 1994
  - AUTONOMOUS OPERATIONS - 1998
- o SYSTEM AUTONOMY CAN BE DEMONSTRATED ON GROUND

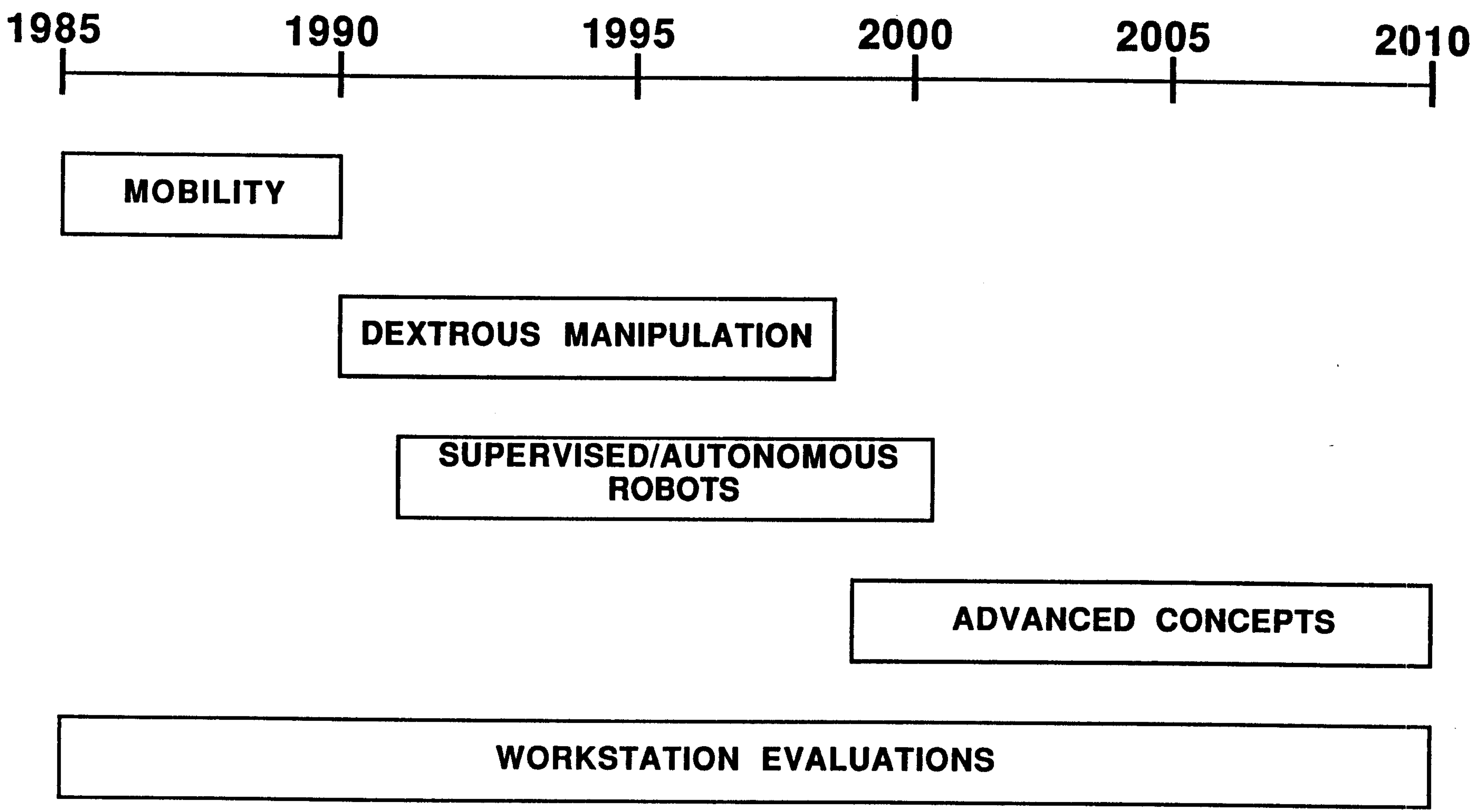
AUTOMATION AND ROBOTICS

WHY IN-SPACE EXPERIMENTS

- EVALUATE ZERO "G" VS. ONE "G" DYNAMICS FOR:
  - MECHANICAL CONFIGURATIONS
  - PROXIMITY OPERATIONS
  - FLUIDS, SOLIDS, GASES
- DEVELOP DESIGN/OPERATIONAL DATA BASE
- VALIDATE PROTO FLIGHT HARDWARE/SOFTWARE/ PROCESSES
- EVALUATE MAN/MACHINE PERFORMANCE ON-ORBIT
- EVALUATE GROUND MODELS/SIMULATIONS
- EVALUATE LONG TERM SPACE EFFECTS ON SYSTEMS

AUTOMATION AND ROBOTICS

EXPERIMENT THRUSTS



AUTOMATION AND ROBOTICS

EXPERIMENT LIST

1988	PROXIMITY MANEUVERING
1989	TELEOPERATED MANEUVERING (MMU)
1990	SMART FRONT AND TECHNOLOGY
1992	SATELLITE SERVICING
1994/6	SUPERVISORY STRUCTURAL ASSEMBLY
1996	IVA ROBOT
2000	AUTONOMOUS SPACE ROBOT
2010	SPACE SPIDER

CONTINUOUS WORKSTATION EVALUATION AND IN-SPACE WORKLOAD MEASUREMENTS

PRE-IOC	IOC (92-97)	FOC (97-BEYOND)
• SINGLE ARM TELEOPERATOR	• DUAL ARM TELEOPERATOR COORDINATION	• MULTI-ARM COORDINATION
• TELEOPERATION FROM EARTH • COMBINED TRANSLATION/ MANIPULATION	• TELEPRESENCE	• AUTONOMOUS ROBOTICS • MULTIPLE ROBOT COORDINATION
• FIXED ON-STATION RMS • DOCKING	• MOBILE ON STATION RMS • TELEOPERATED FREE-FLYING OPERATIONS	• FREE-FLYING AUTONOMOUS PROXIMITY OPERATIONS
	• FREE-FLYER AND DUAL-ARM COLLISION AVOIDANCE	• MULTIPLE ARM COLLISION AVOIDANCE
	• CAD-DRIVEN POSITION REGISTRATION (ON S/S)	
• END-EFFECTOR DEFINITION	• (EVOLVING)	• (EVOLVING)
• MECHANICAL ASSEMBLY PROCESS	• JOINTING	• WELDING
• WORK STATION HW/SW/MM INTERFACES	• (EVOLVING)	• (EVOLVING)
• SENSOR ACCOMMODATIONS	• (EVOLVING)	• (EVOLVING)
• SPACE EFFECTS ON TELEOP. CAPABILITY	• (EVOLVING)	• (EVOLVING)
	• ZERO G MATERIALS HANDLING	• (EVOLVING)

PRE-IOC	IOC (92-97)	FOC (97-BEYOND)
• FAILURE DETECTION • FAILURE ISOLATION • FAULT TOLERANCE	• FAULT TOLERANT (EVOLVING) • FAULT REPAIR	• FAULT REPAIR (EVOLVING)
• ADVANCED AUTOMATION SOFTWARE ALGORITHMS	• REAL-TIME PLANNING • INDEPENDENT EXPERT	• INTERACTIVE AI/EXPERT SYSTEMS
• IMPROVED SATELLITE SERVICING TOOLS	• TELEOPERATOR SATELLITE SERVICING	• AUTONOMOUS SATELLITE SERVICING & REPAIR BY ROBOTS
	• ROBOTIC INSPECTION (SENSOR DEPENDENT)	• ROBOTS REPAIR BY ROBOTS
• WORKLOAD POWER CONSUMPTION EXPERIMENTS		
• ROBOTIC VISION AND IMAGERY OPTIMIZATION	• SPACE EFFECTS ON VISION SYSTEMS	
• AUTONOMOUS ORBIT TRANSFER		
• COMPLIANCE TECHNIQUES	• (EVOLVING)	• (EVOLVING)
• MASS MOVEMENTS STUDIES	• MOMENTUM COORDINATION	• (EVOLVING)
• VOICE CONTROL/INTERACTION	• (EVOLVING)	• (EVOLVING)

AUTOMATION AND ROBOTICS

ACCOMMODATION ISSUES

- "ROBOT FRIENDLY" INTERFACES FOR SERVICING, ASSEMBLY, AND DOCKING
- STANDARD UTILITIES REQUIRED FROM MOBILITY SYSTEMS (RMS, MRMS, OMV, OTV, ETC.)
- SAFETY
- COMPUTING POWER, DATA STORAGE, SYSTEM ARCHITECTURES
- STANDARDS FOR END EFFECTORS, ARMS, HOLDERS, ETC.
- MASS/VOLUME MODEST
- ASTRONAUT TRAINING REQUIRED
- FORMATION FLYING REQUIRED
- EVA NECESSARY IN SOME CASES
- IVA ACTIVITY REQUIRED
- HIGH BANDWIDTH VIDEO/ENCRYPTION COMMUNICATIONS SYSTEM

RECOMMENDATIONS

- ACCELERATE EXPERIMENT SCHEDULE - IMPACT SPACE STATION
- ACTIVE FOLLOW-UP TO EMBED TECHNOLOGY ACCOMMODATION ISSUES WITH SPACE STATION
- ESTABLISHMENT OF IN-SPACE TECHNOLOGY ADVOCACY COMMITTEE
- WORK WITH ULTIMATE USER GROUPS
- ENCOURAGE USERS TO COME FORWARD
- EXPLORE CREATIVE WAYS OF COST SHARING
- DEVELOP AND DISSEMINATE SPACE STATION IN-SPACE RESEARCH CAPABILITY
- BROADEN RESEARCH USER LIAISON WITH STATION
- COORDINATE BETWEEN PANELS - DISTRIBUTE TO PARTICIPANTS
- ESTABLISH CONTINUING MAIL LIST AND FOCAL POINTS

IN–SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

IN–SPACE OPERATIONS

Williamsburg, Virginia
October 8–10, 1985

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IN-SPACE RESEARCH, TECHNOLOGY, AND ENGINEERING WORKSHOP

IN-SPACE OPERATIONS

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IN-SPACE OPERATIONS
SUMMARY
Harold Compton

The In-Space Operations panel was chartered to receive and evaluate TDM proposals in the five areas of:

Advanced Life Support Systems (ALSS

Tethers

Orbital Transfer Vehicles (OTV)

Systems Testing

Propulsion

The panel received twenty-four proposals and, in order to accommodate proposals that did not clearly fit into one of the above areas, the theme areas were expanded to eight to include maintenance and repair, bioresearch, and materials processing. In keeping with the workshop objective, the proposals were categorized as to research, technology, or engineering. Three of the proposals, one in bioresearch and two in materials processing, were considered science and applications, and two were considered inappropriate as TDMs.

The proposals addressed significantly more than the IOC space station. Their requirements for in-space measurements/capability included shuttle and/or free flyers tended by shuttle, build-up or man-tended space station, IOC space station, and growth space station and beyond. Thus the proposals were prioritized as follows:

1 Needed for space station phase C/D

- Precursor shuttle TDM

2 Needed prior to IOC station

- Needed prior to IOC station
- Check-out and build-up phase TDM

3 Needed for growth station and beyond

- Post IOC TDM

4 Enhances operations or capabilities

A. Station

B. Other than station

and annotated according to in-space requirements. It should be noted that some of the proposals required multiple in-space capability, i.e., were shuttle and space station applicable.

In the evaluation of the TDM proposals, the panel noted a common thread, the requirement for a separate and unique research facility, throughout the presentations. These requirements included a propulsion, biomedical research, variable gravity, human research, and space test and evaluation facility. The panel also noted the lack of advanced closed loop environmental life support system (CLESS) TDMs and suggested that such proposals be solicited. The biomedical research TDMs had little in common with in-space operations.

The panel determined that the proposed TDMs have the potential for significant impacts on the space station. Some of the proposals such as the propulsion facility would in themselves produce a contaminated environment. The requirement for a micro or near zero gravity facility might necessitate a free flyer possibly tethered to the station. Large total in-space mass requirements, 40,764 KG alone in 1993, and large power requirements, as much as 35KW for a single experiment, were proposed for the station. Extra vehicular activity (EVA) was found to be modest, but inter-vehicular activity (IVA) was significant, six man years in 1992 alone. Significant scarring of the IOC station will likely be required for OMV and OTV servicing and payload mating facilities.

The panel recommended continuing workshop activity for the advocacy and development of appropriate in-space RT&E TDMs. Perhaps one workshop per year would be sufficient. In any case, the workshop management should emphasize and better define for potential experimenters the TDM concept and the potential RT&E facilities. Advocacy for more DoD involvement should be developed, and a clearing-house activity should be instituted for integrating and coordinating the TDMs. The panel also recommends RT&E experiments advisory committee, co-chaired by OAST and OSS, with representation from DOD, DOE, DOT, SDIO, ACADEMIA, and INDUSTRY. Finally, the panel recommend publication of workshop proceedings or summaries.

IN-SPACE RESEARCH, TECHNOLOGY, AND

ENGINEERING WORKSHOP

IN-SPACE

OPERATIONS

WILLIAMSBURG, VIRGINIA

OCTOBER 8-10, 1985

TDM SUMMARY

RECEIVED 24 TDM PROPOSALS

- 2 LIFE SUPPORT
- 2 TETHER
- 3 OTV
- 3 PROPULSION
- 3 SYSTEM TEST
- 5 MAINTENANCE & REPAIR
- 4 BIORESEARCH
- 2 MATERIAL PROCESSING

3 WERE CONSIDERED SCIENCE & APPLICATIONS ORIENTED

- 1 BIORESEARCH
- 2 MATERIAL PROCESSING

2 WERE CONSIDERED INAPPROPRIATE AS TDMS

- 2 SYSTEM TEST

OBSERVATIONS

- PRESENTATIONS ADDRESSED MORE THAN IOC STATION
- PRESENTATIONS FALL INTO DISTINCT CATEGORIES
  - TECHNOLOGY DEVELOPMENT
  - BASIC RESEARCH
  - CONCEPT DEMONSTRATION/PROOF OF CONCEPT
  - VERIFICATION AND CERTIFICATION
- PRESENTATIONS REQUIRE DIFFERENT IN-SPACE CAPABILITIES
  - SHUTTLE/FREE FLYERS TENDED BY SHUTTLE
  - SPACE STATION; BUILD-UP
  - SPACE STATION; IOC
  - SPACE STATION; GROWTH
- MANY TDM'S REQUIRE OTHER TDM'S AS PRECURSORS
  - ALL PRECURSORS HAVE NOT BEEN IDENTIFIED
  - NEED BOOKKEEPING METHOD TO KEEP TRACK OF SUPPORTING TDM'S

DEFINITION OF PRIORITIES AND CATEGORIES

o PRIORITIES

1. NEEDED FOR SPACE STATION PHASE C/D
   - PRECURSOR SHUTTLE TDM
2. NEEDED PRIOR TO IOC
   - PRECURSOR SHUTTLE TDM OR
   - CHECK-OUT AND BUILD-UP PHASE TDM
3. NEEDED FOR GROWTH STATION AND BEYOND
   - POST IOC TDM
4. ENHANCES OPERATIONS OR CAPABILITIES
   A. STATION
   B. OTHER THAN STATION

o CATEGORIES

- R = RESEARCH, BASIC OR APPLIED
- T = TECHNOLOGY DEVELOPMENT
- E = DEMONSTRATION OF ENGINEERING, CONCEPT, TESTING, OR VERIFICATION

IN-SPACE OPERATIONS - B

PROPULSION

TDM DESCRIPTION	CATEGORY	PRIORITY	SHUTTLE	FACILITY SS - BU	SS - IOC	SS GROWTH	COMMENTS
TDM _____ - LOW THRUST PROP. TECH.	T	4A,B	X	X	X	X	A PROPOSAL FOR A TEST FACILITY. COULD BECOME PRIORITY - 1.
TDM 2322 - LASER PROPULSION	T	4B		X	X	X	PART OF THREE OTHER TDMS
TDM _____ - ION PROPULSION	E	4B	X				SCHEDULED ON A SHUTTLE FLIGHT IN 1986 -
TDM _____ - HIGH ISP ION PROPULSION							NOT PRESENTED
TDM _____ - MPD THRUSTER							NOT PRESENTED
							THESE 5 TDMS SUGGEST A PROPULSION LABORATORY HAS HIGH VALUE - PLUME RESEARCH FACILITY ALSO?

IN-SPACE OPERATIONS - B

OTV

TDM DESCRIPTION	CATEGORY	PRIORITY	SHUTTLE	FACILITY SS - BU	FACILITY SS - IOC	FACILITY SS GROWTH	COMMENTS
TDM-2573 - OTV PROX. OPS	T,E	+3	X	X	X		THESE THREE TDMS AS PROPOSED ARE A MIXTURE OF TECHNOLOGY DEVELOPMENT AND PROCEDURES DEVELOPMENT. TECHNOLOGY DEVELOPMENT TDMS ARE NEEDED EARLIER IN ORDER TO SUPPORT THE OTV DEVELOPMENT SCHEDULE.
TDM-2574 - OTV MAINTENANCE	T,E	+3	X		X		
TDM-2571 - OTV INTERFACING AND TRANSFER	T,E	+3	X		X		- OMV REQUIRED -

IN-SPACE OPERATIONS - B

TETHERS

TDM DESCRIPTION	CATEGORY	PRIORITY	SHUTTLE	FACILITY: SS - BU	FACILITY: SS - IOC	FACILITY: SS GROWTH	COMMENTS
TDM _____ - TETHERED CONSTELLATION	T,E	4A	X	X	X	X	THESE TWO TDMS WERE PROPOSED AS OPERATIONAL SYSTEMS - NOT TDMS - WE NEED TO HAVE "REAL" TDMS FOR TETHER DEVELOPMENT
TDM _____ - TETHERED TRANSPORTATION	T,E	4A	X	X	X	X	

IN-SPACE OPERATIONS - B

SYSTEMS TESTING

TDM DESCRIPTION	CATEGORY	PRIORITY	SHUTTLE	FACILITY SS - BU	FACILITY SS - IOC	FACILITY SS GROWTH	COMMENTS
TDM - STEF - SPACE TEST & EVAL. FACILITY							NOT REALLY A TDM BUT A PROCESS TO IDENTIFY THE REQUIREMENTS FOR TEST AND RESEARCH FACILITIES.
TDM - VARIABLE G EXP. FACILITY	E	4B			X	X	A RESEARCH FACILITY - REQUIRED FOR VEHICLE DESIGN AND HUMAN SPACE ADAPTATIONS FOR MARS AND LUNAR MISSIONS. HIGHLY DESIRABLE FOR OTHER RESEARCH.
TDM - AUTOMATIC SATELLITE C/O EQUIPMENT	E		X				NEEDS ADVOCACY FOR SHUTTLE, MANDATED FOR STATION

IN-SPACE OPERATIONS - B

ADVANCED LIFE SUPPORT

TDM DESCRIPTION	CATEGORY	PRIORITY	SHUTTLE	FACILITY SS - BU	SS - IOC	SS GROWTH	COMMENTS
TDM _____ - CONTAMINANT ANALYSIS	T,E	1	X	X			DEMONSTRATION AND CERTIFICATION OF SPACE STATION CONTAMINATION MONITOR & ATMOSPHERIC PREDICTION MODEL - SPACE STATION SUPPORT?? REQUIRED FOR IOC??
TDM _____ - FIRE SAFETY	T	1	X	X	X		BEGIN W/SHUTTLE TESTS - CONTINUE ON STATION - DEVELOP SAFETY DATA BASE FOR STATION.

IN-SPACE OPERATIONS - B

BIOMEDICAL RESEARCH

TDM DESCRIPTION	CATEGORY	PRIORITY	SHUTTLE	FACILITY: SS - BU	FACILITY: SS - IOC	FACILITY: SS GROWTH	COMMENTS
TDM _____ - DEVELOPMENT OF A BIOREACTOR	T,R	4B	X	X	X	X	SHOULD EVOLVE OR BE A PART OF A HUMAN RESEARCH FACILITY - ? SHOULD THIS BE SCIENCE AND APPLICATIONS
TDM _____ - SURGERY TECHNOLOGY	R	4A,B			X	X	REQUIRES OPERATIONAL HMF
TDM _____ - MEDICAL EXPERIMENTS TECHNOLOGY	R	4A,B			X	X	REQUIRES HUMAN RESEARCH FACILITY AND MAY REQUIRE THE HMF
TDM _____ - CANDIDATE MANNED SYS. EXP.	T	4A,B	X		X	X	A SET OF EXPERIMENTS FOR A HRF - AS PROPOSED, ONLY REQUIRES THE HMF - EQUIPMENT DEVELOPMENT ON SHUTTLE - ALSO INCLUDES QUARTERS MAINTENANCE AND OPERATIONS - HUMAN FACTORS. IT IS VERY DESIRABLE TO PERFORM SOME EXPERIMENTS ON THE SHUTTLE.

IN-SPACE OPERATIONS - B

MAINTENANCE AND REPAIR

TDM DESCRIPTION	CATEGORY	PRIORITY	FACILITY					COMMENTS
			SHUTTLE	SS - BU	SS - IOC	SS GROWTH		
TDM-2581 - SYSTEMS OPERATIONAL MAINTENANCE	T,E	4A	X	X	X	X		THE PROPOSED TDM IS NOT CLEAR - IT DOES TELL US THAT WE NEED A FACILITY FOR MAINTENANCE TECHNOLOGY DEVELOPMENT AND ENG. DEV.
TDM-2561 - SATELLITE MAINTENANCE AND REPAIR	E	4A			X	X		OMV REQUIRED - MANY TDM PRECURSORS REQUIRED FOR TECHNOLOGY DEVELOPMENT - THIS AND TDM 2563, ARE ENGINEERING VERIFICATION & PROOF OF CONCEPT
TDM-2563 - MATERIALS RESUPPLY	E	4A			X	X		OMV W/KITS REQUIRED - PRECURSORS REQUIRED.
TDM-2564 - COATING MAINTENANCE AND REPAIR	T	3	X	X	X	X		DEMONSTRATE INSTRUMENT ON SHUTTLE; OPERATIONAL AS EARLY AS POSSIBLE - IMPACT GROWTH STATION.
TDM _____ - ON-ORBIT WELDING	T	4A	X	X	X	X		CURRENT PLANS ARE FOR A SHUTTLE TEST - SOME FOLLOW-ON TESTING COULD BE DONE ON SPACE STATION.

IN-SPACE OPERATIONS - B

MATERIAL PROCESSING TDMS

TDM DESCRIPTION	CATEGORY	PRIORITY	SHUTTLE	FACILITY SS - BU	FACILITY SS - IOC	FACILITY SS GROWTH	COMMENTS
TDM _____ - CRYSTAL GROWING							THIS TDM IS TO FIRST DO SOME TECHNOLOGY DEVELOPMENT, BUT IS MOSTLY PROOF OF CONCEPT.
TDM _____ - FLUIDIZED BED							SUPPORTS MATERIALS PROCESSING IN SPACE AND ON OTHER PLANETARY SURFACES

FINDINGS

- o TDMS ARE "FALLING" INTO GROUPS THAT ARE MAKING SEVERAL RESEARCH AND TEST FACILITIES VIABLE OPTIONS
  - PROPULSION RESEARCH FACILITY
    - o THRUSTER RESEARCH
    - o FLUID HANDLING & TRANSFER
    - o PLUME AND CONTAMINATION MEASUREMENT
  - BIOMEDICAL RESEARCH FACILITY
  - TETHER DEVELOPMENT AND PROOF OF CONCEPT
  - VARIABLE G RESEARCH FACILITY
  - HUMAN RESEARCH FACILITY
  - SPACE TEST AND EVALUATION FACILITY (?) (?)
- o MISSING
  - ADVANCED CELSS TECHNOLOGY DEVELOPMENT
    - o NEED CELSS RESEARCH FACILITY
  - TDM ENGINEERING DEMO OF OMV
- o EXTRA - BIOMEDICAL RESEARCH
  - HUMAN MEDICAL RESEARCH
  - HUMAN FACTORS RESEARCH
  - BIOREACTOR

SPACE STATION IMPACTS

- CONTAMINATION ENVIRONMENT - RESOLUTION: FREE FLYER
- ACCELERATION ENVIRONMENT - RESOLUTION: FREE FLYER
- LARGE MASSES (1993: 40,764 KG)
- POWER REQUIREMENTS CAN BE HIGH
  - AS MUCH AS 35 KW FOR SINGLE EXPERIMENT
    - SHORT DURATION - ENERGY STORAGE TECHNIQUES MAY RESOLVE
- EVA IS MODEST BUT NOT NEGLIGIBLE
- IVA IS SIGNIFICANT - 1992 - 6 MAN YEARS
- OMV AND OTV UTILIZATION IS MODEST
- SIGNIFICANT "SCAR" MAY BE REQUIRED
  - FOR FACILITIES

RECOMMENDATIONS

- o DEVELOP A FORMALIZED SYSTEMS APPROACH TO TDM DEFINITIONS
  - INVITED PAPERS DOES NOT ENSURE COMPLETENESS
  - GOVERNMENT/INDUSTRY/UNIVERSITY ADVISORY GROUP
- o WORKSHOP SHOULD CONTINUE BUT SHIFT IN EMPHASIS
  - CONCEPT DEVELOPMENT
  - PLANNING (DOCUMENT)
  - PRIORITIZING
  - INTEGRATION AND COORDINATION
- o IMPROVE DOD INVOLVEMENT
- o DEVELOP DEFINITION OF RT&E FACILITIES

RECOMMENDATION FOR CONTINUING ACTIVITY

- NEED
  - CLEARING HOUSE ACTIVITY FOR TDMS
  - INTEGRATING AND COORDINATING FOCAL POINT
  - A MANAGEMENT AND PLANNING MECHANISM FOR OAST
  - IMPACTS ASSESSMENTS FOR SPACE STATION OFFICE
- RECOMMEND
  - IN-SPACE RT&E ADVISORY COMMITTEE
  - LEAD - OAST AND OSS
    - OTHER GOVT.: DOD, DOE, DOT, SDIO
    - ACADEMIA
    - INDUSTRY
  - FUNCTIONS
    - TDM REQUIREMENTS DOCUMENT
    - DEFINITION OF FACILITIES
    - DETERMINATION OF SPACE STATION IMPACTS
    - PLANNING AND CONDUCTING SYMPOSIA
    - PRIORITIZING AND CATEGORIZING TDMS
    - RECOMMENDATIONS TO OAST FOR BUDGET AND SCHEDULES
- YEARLY SYMPOSIUM
  - PUBLISHED VOLUMES